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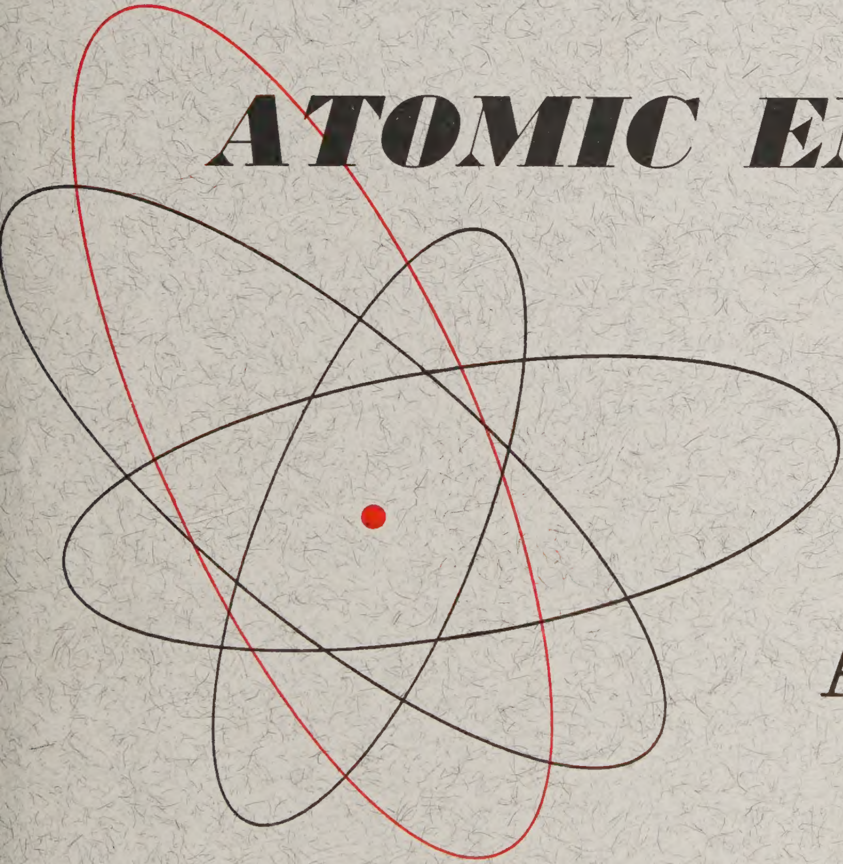

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CONTEMPORARY PROBLEMS OF METALLURGY

Edited by A. M. Samarin

TRANSLATED FROM RUSSIAN

(Original published by the Academy of Sciences USSR Press)

CONTEMPORARY PROBLEMS OF METALLURGY was selected for translation into English by the Board of Governors of Acta Metallurgica since it offers Western scientists a comprehensive review of the most significant research and industrial applications in the field of metallurgy developed in the Soviet Union. This volume, in addition to detailing the recent Soviet developments in this field, contains two chapters which outline achievements in China and in East Germany.

Soviet advances in the production of steel and pig iron are discussed at length. Heat-resistant, austitic, and stainless steels have been subjected to a great deal of research in the USSR and data on various heat treatments and their effects on steel structures have been collected. These methods and the many others detailed in this book assure its value to all Western scientists and technologists concerned with metallurgical problems.

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ABRAM FEDOROVICH IOFFE

October 29, 1880—October 10, 1960

Just when the physicists of our country were preparing to celebrate the eightieth birthday of their teacher—Academician Abram Fedorovich Ioffe—the tragic news of his sudden death arrived.

A. F. Ioffe represented the whole epoch of the development of physics in our country. Starting out on his scientific career at the beginning of this century, he pursued it untiringly up to the last days of his life.

A. F. Ioffe, one of the greatest physicists of our country, has left an immense scientific heritage. His studies cover very wide and diverse fields of physics.

A. F. Ioffe's doctoral dissertation, completed in the laboratory of the renowned physicist W. K. Roentgen, was devoted to investigations of the elastic aftereffect in crystals. This work and the experimental methods used in its execution aroused in Abram Fedorovich a great interest in the study of the mechanical and electrical properties of dielectric crystals. In this field A. F. Ioffe made very important discoveries, many of which became classical examples and are expounded in physics courses. We need only mention the well-known Ioffe effect—the hardening of a rock salt crystal when its surface is dissolved in water, the discovery of asterism, consisting in the doubling of the spots on the Laue diagram when plastic deformation sets in, the well-known experiments on high-voltage polarization of dielectrics, and so on. The works of A. F. Ioffe in this field laid the foundation for new lines of research in solid state physics, lines which are being successfully developed by his pupils.

Abram Fedorovich is responsible for fundamental studies on general questions of physics. His classical experiments on the measurement of the electron charge and the quantum nature of light have for long become the property of world science. Models of these experiments are demonstrated at lectures and have become part of students' practical courses.

In the late twenties, when A. F. Ioffe with a group of his pupils began to carry out his planned program in the field of semiconductors, there were few who understood their immense scientific and technical importance. The exceptional breadth of his scientific outlook and the extraordinary gift of scientific foresight enabled Abram Fedorovich, as far back as 30 years ago, to realize that semiconductors would play a very important role in engineering. One of Abram Fedorovich's papers, written in 1931, was entitled "Semiconductors—a new material for electrical engineering." In the last decade A. F. Ioffe has put forward several valuable ideas on the use of semiconductors for power generation.

A. F. Ioffe was deeply convinced that the sacred duty of the scientist was to work for the welfare of the people.

A. F. Ioffe's scientific services, which won him fame as an outstanding representative of the physics of this century, were not his only great contribution. His services in the matter of educating a whole galaxy of Soviet physicists are also inestimable.

While in the twenties A. F. Ioffe could be proud of the fact that his first pupils had their own pupils, by the end of his life numerous physical institutes of the Soviet Union were filled by the fourth and fifth generation of his pupils. A. F. Ioffe's school produced some of the greatest Soviet physicists. They include more than 30 Academicians and Corresponding Members of the Academy of Sciences. Many of them have become directors of large scientific institutes. The majority of physicists who have directed and are directing research in the field of nuclear physics and nuclear engineering were pupils of Abram Fedorovich. It is impossible to imagine what difficulties we would have encountered if we had not had at the necessary time a large team of scientists able to resolve the most important problems in this field.

The services of A. F. Ioffe in creating a school of Soviet physicists have received general recognition and have been highly evaluated by the Soviet government and the entire Soviet community. A. F. Ioffe's work in organizing a wide network of scientific research institutes in our country merits special recognition. A. F. Ioffe considered it vitally necessary to create an integral system of physics and engineering institutes and factory laboratories, which would provide a scientific basis for our developing industry. In this task he enjoyed the broad support of the Soviet government.

The Leningrad Institute of Physics and Technology, set up as long ago as 1919 and directed by Abram Fedorovich for 30 years, has become known the world over. It was in this institute in the early thirties that the foundations for the extensive development of research on the physics of the atomic nucleus were laid.

We know that with the direct participation of Abram Fedorovich and under his guidance 16 scientific institutes were set up in a comparatively short time in several of the large industrial centers of the Soviet Union. For each of them Abram Fedorovich picked out from his pupils a group of qualified scientific workers who formed the nucleus of the new institutes. The most recent was the Institute of Semiconductors, which A. F. Ioffe directed and in which he worked till the end of his life.

A. F. Ioffe was elected to the Academy of Sciences, USSR, in 1920. As Vice-President and Member of the Presidium, he had a great influence on the work of the Academy. The Soviet government recognized the outstanding services of A. F. Ioffe in the development of science; in 1955 he was awarded the title of Hero of Socialist Labor.

A. F. Ioffe won for himself the deep respect of scientists in all countries of the world. This was manifested in his election as a member of academies of sciences and scientific societies in many countries, and in the conferring of numerous honorary scientific titles on him.

The life of Abram Fedorovich was cut off at a time when he was imbued with new scientific ideas and plans. His numerous friends, pupils and colleagues, and the entire Soviet community deeply mourn the heavy loss inflicted on Soviet and world science.

USE OF THE (α, n) REACTION FOR THE QUANTITATIVE DETERMINATION OF THE BERYLLIUM, BORON AND FLUORINE CONTENT OF CONCENTRATION PRODUCTS

I. N. Plaksin, V. N. Smirnov and L. P. Starchik

Translated from Atomnaya Énergiya, Vol. 9, No. 5,
pp. 361-365, November, 1960
Original article submitted January 21, 1960

A rapid method for the quantitative analysis of the beryllium, boron and fluorine contents in concentration products, based on the use of the (α,n) reaction, is described. Po^{210} with an activity of 250 μCwas used as the α-radiation source. The number of neutrons in the concentration products knocked out by α-particles is recorded by a neutron counter and serves as a measure of the beryllium, boron, and fluorine content in the product analyzed. The method makes it possible to check the concentration products of beryllium, fluorite and boron ores, and also rich ores containing fluorine and boron, with an accuracy up to 1.5-2%. The content of the element checked can be determined in the presence of a constant amount of admixtures of other elements with a high (α,n) reaction yield.

During the technological treatment of ores it is necessary to check the results of concentration in stages in order to control the process. Existing chemical and spectral methods of analysis are complex and lengthy. The development of a rapid method of analysis of ores and concentration products is therefore of particular importance.

Such methods can be achieved on the basis of radioactive radiations. By means of induced activity, excited by neutrons, the content of various elements in ores and rocks can be determined. The neutron activation analysis of rocks and ores, for the determination of their aluminum, manganese, vanadium and silicon contents, was described in [1]. The radiation of a radioactive isotope, obtained as a result of a nuclear reaction, is recorded by means of the use of induced activity.

To obtain an isotope with an artificial activity sufficient for analysis, multicurie sources are necessary, and when isotopes with a long half life are used the sources must have a protracted activation time. The secondary radiation occurring as a result of the nuclear reaction itself is recorded when nuclear reactions are used.

A photonuclear (γ,n) reaction, in which neutrons were produced by the irradiation of beryllium with hard γ-rays of radium, was used in [2] for the quantitative analysis of the beryllium content in ores. Similar experiments, with the use of Sb^{124} γ-radiation, were carried out in [3].* This nuclear reaction is advantageous by reason of the fact that with a γ-ray energy of 1.63-2.2 Mev, neutrons are only knocked out from beryllium, because the photonuclear threshold for the other elements is much higher. The inconvenience of this reaction for industrial purposes arises from the necessity of using high-energy γ-radiation with a high activity, which requires special precautions and cumbersome protective apparatus during operations.

The use of the (γ,n) reaction for the determination of the beryllium content in ores, concentration products [4, 5] and natural ore deposits has become widespread in the USSR.

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*[3] was published in 1951, and [2] in 1957, but the work indicated in these reports was carried out in 1940.

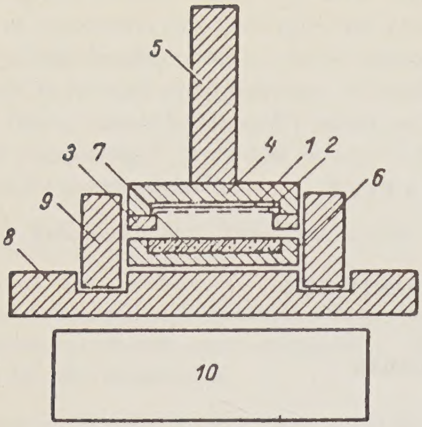

Fig. 1. Apparatus for the quantitative determination of the concentration products of ores by bombarding with α-particles: 1) platinum foil; 2) polonium layer; 3) clamping ring; 4) ebonite holder; 5) handle; 6) cassette; 7) product to be checked; 8) table; 9) centering ring; 10) neutron counter.

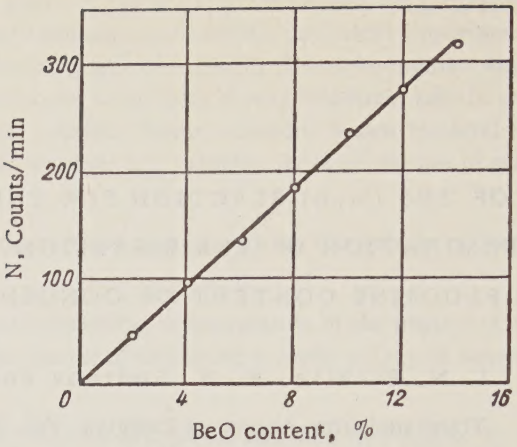

Fig. 2. Calibration curve for a mixture of beryllium, quartz and feldspar (quartz/feldspar ratio 2:1).

To determine the boron content in ores and concentration products, a method based on the absorption of slow neutrons in the sample analyzed is used [6]. This method is employed for the determination of the boron content in rocks [7, 8] and for measuring this content during the sinking of boreholes [9].

The use of the (α,n) reaction, in which neutrons are emitted as a result of irradiation of the substance with α-particles, opens up interesting possibilities for the quantitative determination of concentration products. A number of elements of the periodic system have fairly large effective (α,n) reaction cross sections, which allows a quantitative determination to be made of these elements in concentration products and ores. To determine the beryllium content in biological tissue [10] and aerosols [11], the γ-radiation accompanying a (α, nγ) nuclear reaction was previously employed.

For a quantitative check of concentrates during the concentration of beryllium ores, we [12] used the nuclear reaction $Be^9 + Ne^4 \rightarrow C^{12} + n^1$. The yield of the (α, n) reaction for beryllium is greater than for other elemetns and is equal to 80 neutrons for each 10^6 α-particles of Po^{210} [13].

To check fluorite ores and their concentration products, the nuclear reaction $F^{19} + He^4 \rightarrow Na^{22} + n^1$, with a yield of 12 neutrons per 10^6 α-particles, is used.

The boron content in concentration products was determined by the nuclear reactions

$$B^{10} + He^4 \rightarrow N^{13} + n^1$$

and

$$B^{11} + He^4 \rightarrow N^{14} + n^1.$$

The yield of the nuclear reaction for boron is 24 neutrons per 10^6 α-particles.

The other elements found in ores have a considerably lower neutron yield per 10^6 α particles: aluminum 0.74 neutrons, silicon 0.16, carbon 0.11, oxygen 0.07. Hence, in the concentration products of beryllium, fluorite and boron ores the number of neutrons knocked out by α-particles must be proportional to the beryllium, boron and fluorine content.

A Po^{210} isotope was used as an α-radiation source for bombarding the concentration products. It has a half life of 138.3 days, an α-radiation energy of 5.3 Mev and a maximum α-particle range of 3.8 cm in air (under normal conditions). Po^{210} is a convenient α-radiation source, because during the decay of polonium only comparatively weak γ-radiation (one gamma-ray quantum per 10^5 α-particles) is observed; as a result of this, it is relatively easy to handle this source.

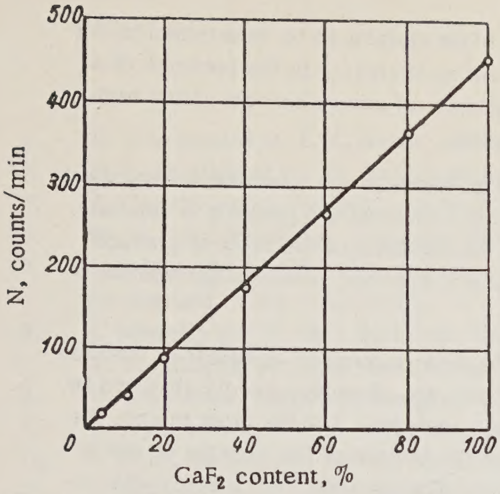

Fig. 3. Calibration curve for a mixture of fluorite, quartz and barite (quartz/barite ratio 5:2).

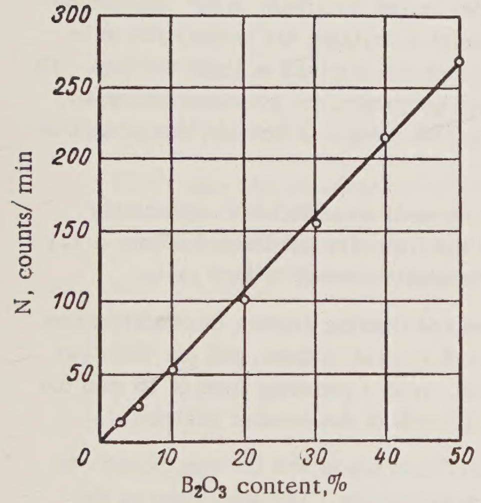

Fig. 4. Calibration curve for a mixture of hydroboracite and gypsum.

The α-radiation source was prepared by coating the surface of platinum foil with polonium by the vacuum sublimation method. The amount of polonium deposited on the platinum foil was assessed by the intensity of its α-radiation, and was 250 μC [14].

The apparatus shown in Fig. 1 was used for the experiments on the determination of the beryllium, boron and fluorine content in concentration products by means of the (α, n) reaction. The platinum foil with its coating of polonium was fixed in an ebonite holder by a clamping ring. The cassette with the concentration products was installed on the table and fixed by a centering ring. The α-source for knocking out neutrons from the product analyzed was placed on the cassette. The neutron count was carried out by means of a neutron counter.

The polonium source used in our work contaminates the cassettes and the analyzed products with polonium. To prevent contamination the polonium layer must be covered with a protective film of thin foil which does not absorb α-radiation, or a film of this type must be applied to the surface of the polonium source. In this case, as a result of the loss of energy of the α-particles in the film the neutron yield decreases. The reduction in the intensity of the neutron current may be compensated by placing the polonium source and the cassette containing the preparation inside a paraffin block, and increasing the number of boron counters in the block. The use of a paraffin block and three boron counters gives a five-fold increase in the neutron count.

The determination of the beryllium, boron and fluorine content is carried out by means of calibration curves, plotted for standard mixtures with a known content of these elements. From the calibration curve of Fig. 2 it is seen that with a beryllium oxide content up to 14 wt% the number of neutrons emitted during bombardment with α-particles is directly proportional to the beryllium concentration. The fluorine content in fluorite (48.8 wt %) is considerably greater than the beryllium content in beryl (14.1 wt %). Hence, in spite of the lower yield of the (α, n) reaction for fluorine the number of neutrons knocked out from fluorite is sufficient to determine the fluorine content in the product analyzed (Fig. 3). The fluorite content in the initial ore is usually fairly high; this method can, therefore, be used to determine the fluorite content in the initial ore as well as in concentration products. The calibration curve shown in Fig. 4 was obtained by measuring the boron oxide content in a mixture of hydroboracite and gypsum.

The neutron yield of the (α, n) reaction for boron is approximately 3.3-fold lower than for beryllium, but the boron content in hydroboracite is roughly 3.3 times greater than the beryllium content. This makes it possible to determine the amount of boron oxide in concentration products and in rich ores.

The particle size of the flotation products does not have an appreciable influence on the number of neutrons knocked out, because all the α-particles emitted by the source in the direction of the analyzed sample are absorbed by the latter.

During the determination of the beryllium, boron and fluorine content in concentration products with a particle size of -35 +325 mesh (four size classes) the variations in the neutron count are within the limits of experimental error.

The influence of admixtures of elements with a high (α, n) reaction yield was investigated for mixtures of fluorite and beryl, diluted with quartz and feldspar. With a constant content of admixture in the product to be analyzed the calibration curve does not lose its linear character but is displaced parallel to itself by a value directly proportional to the amount of admixture in the product (Fig. 5).

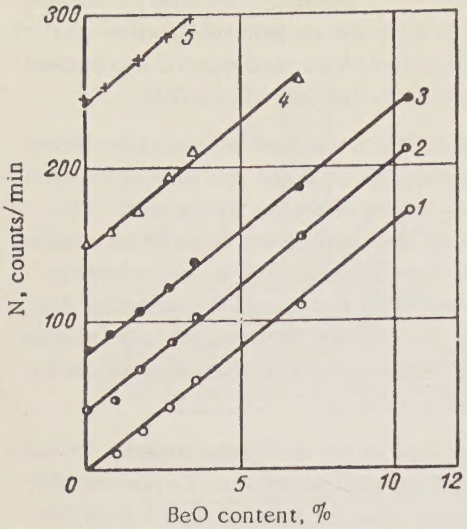

Fig. 5. Relation between the neutron count and the beryllium oxide content at different fluorite concentrations (in %): 1) 0; 2) 12.5; 3) 25; 4) 50; 5) 75.

Thus, the content of the element to be determined in the concentration products can be evaluated in the presence of a constant amount of admixtures of other elements with a high yield of the (α, n) reaction.

The path of the α-particles in the substance is very short and for Po^{210} α-particles in concentration products is approximately 20μ. Hence, if the thickness of the layer of product analyzed is more than 20μ it does not influence the number of neutrons knocked out.

The neutrons produced as a result of this nuclear reaction are mainly fast neutrons and are, therefore, hardly absorbed in the layer of product being analyzed. For the same reason, the material and thickness of the bottom of the cassette do not influence the neutron count. The distance from the α-source to the product analyzed has a substantial influence on the number of neutrons knocked out. When this distance varies by 250 μ the neutron count varies by 5-7%; it is, therefore, necessary to maintain identical irradiation geometry with the smallest possible distance between the α-source and the product analyzed. The energy loss of the α-particles during their path in air from the polonium source to the cassette containing the preparation to be analyzed is not high, because this distance is about 0.5 mm. To reduce the energy loss of the α-particles and the error due to the irradiation geometry, the polonium source and the cassette with the preparation can be located in a vacuum chamber, but this leads to a considerable complication of the irradiation apparatus.

The analysis of moist products is complicated by the fact that the current of α-particles is appreciably weakened by the film of water on the surface of the product analyzed and the film of water formed on the α-ray source as a result of the condensation of the water vapor contained in the product analyzed.

The error occurring during the determination of the beryllium, boron and fluorine content in concentration products by this method is due to the statistical distribution of the pulses with respect to time, and the variation in the counting geometry and the selection of the mean sample for analysis. With a counting time of 15 min the error in the determination of the beryllium, boron and fluorine content is 1.5-2% of the content analyzed.

The method of rapid analysis makes it possible to determine the beryllium, boron and fluorine content in concentration products quickly and with sufficient accuracy for practical requirements. The advantage of the proposed control method is its simplicity and safety compared with the previously proposed method [2, 3], based on the photonuclear reaction with the use of hard gamma rays of high activity. The use of a small amount of the product to be analyzed (several grams) and the fact that the sample need not be weighed are further advantages.

This method may be used for determining the beryllium and boron content in alloys and, in view of its simplicity, for the analysis of ores under field conditions during prospecting for mineral products.

The measurement of the beryllium and boron content in metallic alloys is simplified by the fact that perfect identity of the neutron count geometry can readily be obtained for metals. For this purpose the surface of the metal sample must be flat, which is ensured by polishing.

The beryllium and boron content is determined by placing an α-particle source directly on the flat surface of the sample of alloys, located in a neutron counter. Since the result of the (α, n) reaction is the production of fast neutrons, which are not appreciably absorbed in the substance, the thickness of the sample (when it is less than 1 cm) will not influence the determination of the content of the elements if the counting geometry remains unchanged.

To measure the content of elements in alloys, the samples used must have a known content of elements used as standards.

When the beryllium content in alloys containing aluminum is determined, the count of neutrons produced in the aluminum can be taken into consideration after the measurement of its positron activity induced by the α-particles [15].

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

BLOCK REPLACEMENT IN A TWO-DIMENSIONAL SQUARE LATTICE*

L. Trlifai, I. Rochek

Institute for Nuclear Research, Ch. S. A. N., Prague

Translated from Atomnaya Énergiya, Vol. 9, No. 5, pp. 366-374, November, 1960
Original article submitted Jan. 28, 1960

In this paper the results of the investigation of the replacement of a block in an infinite two-dimensional homogeneous square lattice by a block with different physical properties are presented. In inactive media the solution is analogous to the solution given in [1]; for multiplying media a somewhat modified method of solution is proposed, which method is employed in the quantum theory of fields [2]. The case of a critical infinite lattice is examined as the limiting case of the two preceding. When the homogenization conditions are fulfilled, results are obtained corresponding to the homogeneous analog of the problem considered.

INTRODUCTION

The heterogeneous method worked out by A. D. Galanin, S. M. Feinberg, and others is of great value in the solution of many problems in the theory of thermal heterogeneous nuclear reactors. It has been used with success in determining the critical conditions for heterogeneous reactors with simple and complicated lattices, and also in determining the effective boundary conditions [1, 3]. Problems of the latter type also include calculating the change in neutron density distribution, the critical dimensions, etc., caused by replacing one fuel block in the lattice by a block with different characteristics (with a regulator and so on). This problem was solved in [3] for a three-dimensional lattice consisting of point blocks. However, a problem more important from the practical point of view is the analogous problem in a two-dimensional lattice of cylindrical blocks. In [4] this problem is solved for an infinite cylindrical reactor with square cross section and a square lattice. For a two-dimensional lattice the method of solution by Feinberg may not be employed immediately; but the solution of Mets, more complicated mathematically, may successfully be applied but only for small numbers of blocks. In the method proposed, these difficulties are removed.

For simplicity we consider a two-dimensional infinite square lattice, formed by unbounded line blocks. As in [1], we assume that the finite character of the transverse dimensions of the blocks may be taken into account by introducing effective constants. We assume also that for the slowing down and diffusion of thermal neutrons, the diffusion-growth approximation is applicable, and that the absorption of resonance neutrons in blocks may be neglected.

In order to find the density distribution for neutrons in the lattice, it is sufficient to know the density of thermal neutrons on the surfaces of the individual lattice blocks. In the case of a square lattice with mesh width $\underline{a}$, the density N is a function of $\mathbf{k}a$, where $\mathbf{k}a$ indicates the position of the block in the plane perpendicular to the block; $\mathbf{k}$ is a two-dimensional vector with components which are whole numbers. If one effects a block replacement at the place where $\mathbf{k} = 0$, then $N(\mathbf{k}a)$ satisfies the following system of equations [1]:

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$$N(\boldsymbol{k}a)=\sum_{\boldsymbol{k}'}H_0(|\boldsymbol{k}-\boldsymbol{k}'|a)N(\boldsymbol{k}'a)+ \\ +h(|\boldsymbol{k}|a)N(0), \tag{1}$$

where

$$h(|\boldsymbol{k}|a)=H_1(|\boldsymbol{k}|a)-H_0(|\boldsymbol{k}|a). \tag{2}$$

The last term is the perturbation due to the block replacement at the point $\mathbf{k}=0$. The functions H_0 and H_1 may be expressed with the help of integral kernels of the form [1]:

$$H_j(|\boldsymbol{r}|)=\left(\frac{a}{2\pi}\right)^2\frac{1}{q_{0j}}\iint\limits_{-\infty}^{\infty}d\omega\,\frac{\exp\{ir\omega\}}{1+L^2\omega^2}\times \\ \times(\eta_j\exp\{-\omega^2\tau\}-1). \tag{3}$$

Here the diffusion length for thermal neutrons L and the slowing down length of neutrons $\sqrt{\tau}$ refer to the retardant, whereas the quantity $q_{0j}(j=0.1)$, characterizing the internal block-effect, and the effective value of the number of secondary neutrons η_j refer to the block of type j ($j=0$ for the fuel block, $j=1$ for a replaced block).

We now recall some known results from [1]. The solution for an infinite lattice without perturbation ($h=0$) is unchanged upon shifting by the amount $\mathbf{n}a$; the function $H_0(|\mathbf{k}-\mathbf{k}'|a)$ commutes with the operators corresponding to the elementary displacements given by the vectors $(a, 0)$ and $(0, a)$. Consequently the same system of eigenfunctions correspond to the commuting displacement operators and to H_0. From the point of view of the operator H_0 the following cases may occur:

a) Active medium. A stationary chain reaction takes place in a finite portion of the lattice.

The solution of equation (1) with $h\equiv 0$ will be

$$N(\boldsymbol{k}a)=C(\varkappa)\exp\{i\varkappa\boldsymbol{k}a\}, \tag{4}$$

where $\varkappa$ is the Laplacian (material parameter) of the active medium. It is determined from the relation $F_0(\kappa)=1$, which may be written, when the "homogenization" condition is fulfilled [1], as:

$$q_{0j}(1+L^2\varkappa^2)F_j(\varkappa)\equiv\eta_j\exp\{-\varkappa^2\tau\}-1-q_{1j}(1+L^2\varkappa^2)=q_{0j}(1+L^2\varkappa^2), \tag{5}$$

where

$$F_j(\varkappa)\equiv\sum_{k}H_j(|k|a)\exp\{i\varkappa ka\}=\frac{1}{q_{0j}}\sum_{\boldsymbol{\nu}}\frac{\eta_j\exp\left\{\frac{4\pi^2\tau}{a^2}\left(\boldsymbol{\nu}+\frac{a}{2\pi}\varkappa\right)^2\right\}-\exp\left\{\frac{2\pi i}{a}r\boldsymbol{\nu}\right\}}{1+\frac{4\pi^2L^2}{a^2}\left(\boldsymbol{\nu}+\frac{a}{2\pi}\varkappa\right)^2} \tag{6}$$

and $q_{1j}(j=0.1)$ expresses the external block-effect for the j-th block. Equation (5) clearly determines only the magnitude of the Laplacian $|\boldsymbol{\kappa}|=\kappa$.

b) Critical medium. The general solution will be

$$N(\boldsymbol{k}a)=C+\boldsymbol{A}\boldsymbol{k}a, \tag{7}$$

where the constant C and vector **A** are arbitrary; the second part of this solution corresponds to the external source of neutrons. The lattice parameters should be, clearly, such that the equation $\sum\limits_{k}H_0(|k|a)=1$ remains valid.

c) Inactive medium. An external neutron source is necessary to sustain a chain reaction in an infinite lattice. The following is a solution of equation (1) with $h\equiv 0$ (sources at infinity):

$$N(\boldsymbol{k}a)=C(\varkappa)\exp\{\varkappa\boldsymbol{k}a\}. \tag{8}$$

The real part of the vector $\boldsymbol{\varkappa}$ is determined from the condition $F_0(i\mathbf{k})=1$.

When the "homogenization" condition is fulfilled, we obtain an approximate equation for $\mathbf{k}$, if in (5) $\mathbf{k}$ is replaced by $i\boldsymbol{\varkappa}$. We should clearly have $L^2\boldsymbol{\varkappa}^2<1$.

Further, we consider the perturbation at the point $\mathbf{k}=0$, due to replacing the block 0 by the block 1.

1. Feinberg's method for an inactive medium.

We examine a cylindrical block absorbing thermal neutrons in an infinite inactive homogeneous medium. A cylindrically symmetric thermal neutron source is at infinity. In this case the density of thermal neutrons at a large distance from the block may be separated into two parts: one corresponds to the external source and rises steadily when the distance from the source is increased; the second corresponds to the absorption of neutrons in a block and very rapidly decreases with distance. Equation (1) reflects this absorption for a heterogeneous medium, if the lattice is inactive.

Therefore, we may separate the solution to equation (1) sought for into two parts:

$$N(\mathbf{k}a) = A(\mathbf{k}a) + n(\mathbf{k}a). \tag{9}$$

The first part should satisfy equation (1) without perturbation

$$A(\mathbf{k}a) = \sum_{\mathbf{k}'} H_0(|\mathbf{k}-\mathbf{k}'|a)\,A(\mathbf{k}'a). \tag{10}$$

Solution (10) should be cylindrically symmetric, since the block is at the origin and the neutron source is cylindrically symmetric. Therefore, if the conditions of homogenization are satisfied in the lattice, the expression for A(**k**a) may be represented in the form of a linear combination of solutions (8)

$$A(\mathbf{k}a) = \frac{A(0)}{2\pi}\int_{\beta}^{2\pi+\beta} d\varphi \exp\{\varkappa \mathbf{k}a\} = \\ = A(0)\,I_0(\varkappa|\mathbf{k}|a). \tag{11}$$

The latter relation is the integral representation of Bessel's function of an imaginary argument of the first kind of zeroth order.

From equations (9), (10) and (1) for (**k**a) the following equation is valid:

$$n(\mathbf{k}a) = \sum_{\mathbf{k}'} H_0(|\mathbf{k}-\mathbf{k}'|a)\,n(\mathbf{k}'a) + h(|\mathbf{k}|a)\,N(0). \tag{12}$$

By assumption n(**k**a) is everywhere finite and as $|\mathbf{k}|a \to \infty$ it rapidly decreases. Therefore, for the solution to equation (12) one may apply Feinberg's method [3]. We introduce the following functions:

$$\sum_{\mathbf{k}} \exp\{ia\mathbf{k}\omega\}\,n(\mathbf{k}a) = q(\omega), \tag{13a}$$

$$\sum_{\mathbf{k}} \exp\{ia\mathbf{k}\omega\}\,H_j(|\mathbf{k}|a) = F_j(\omega), \quad (j = 0, 1), \tag{13b}$$

$$F_1(\omega) - F_0(\omega) = f(\omega). \tag{13c}$$

Then from equation (12) it follows that

$$q(\omega) = N(0)\frac{f(\omega)}{1-F_0(\omega)}\,. \tag{14}$$

The denominator in (14) is never zero (blocks with index 0 are inactive). From (13a) and (14) one may easily determine the Fourier coefficients n(**k** a). However, we write immediately the complete expression for the density N(**k**a). After a few transformations from (9), (11), and (14) we obtain

$$N(\mathbf{k}a) = N(0)\left\{I_0(\varkappa|\mathbf{k}|a) + \left(\frac{a}{2\pi}\right)^2 \iint\limits_{\text{period}} d\omega\,\frac{f(\omega)}{1-F_0(\omega)} \times \left[\exp\{-ia\mathbf{k}\omega\} - I_0(\varkappa|\mathbf{k}|a)\right]\right\}. \tag{15}$$

In this expression one integrates over the area of a cell of the reciprocal lattice; i.e., over a square of side $\frac{2\pi}{a}$ (the center of the square is at the origin of the ω_1 and ω_2 coordinate system).

Expression (15) is a solution to equation (1) satisfying the homogenization condition for the lattice. For small |**k**| further simplification of it is impossible. For such values at |**k**| the neutron density is more conveniently determined by numerical methods from the initial equation (12), and not from the formula (15). For large values |**k**| one may find an asymptotic formula, which is of interest also from the physical point of view.

For large |**k**| in the first integral of expression (15), only the region of integration for small ω^2 plays an important role. For small values of ω^2 in the first approximation, corresponding to equation (5) one may write

$$q_{0j}(1+L^2\omega^2)[1-F_j(\omega)] = \mu_j + V_j\omega^2, \quad (j=0, 1), \quad \mu_j = q_{0j} + q_{1j} + 1 - \eta_j, \quad v_j = L^2(q_{0j}+q_{1j}) + \eta_j\tau, \tag{16}$$

so that, corresponding to (13b) and (13c) we obtain the following from (14):

$$\frac{f(\omega)}{1-F_0(\omega)}=\left[1-\frac{q_{00}}{q_{01}}\frac{v_1}{v_0}\right]-\frac{q_{00}}{q_{01}}\frac{\mu_1-\mu_0\frac{v_1}{v_0}}{v_0\omega^2+\mu_0}\,. \tag{17}$$

Since

$$\frac{a^2}{(2\pi)^2}\iint\limits_{\text{period}} d\omega \exp\{iah\omega\}=\delta_{h,\,0},$$

where $\delta_{h,0}$–is the Kronecker symbol, it is necessary only to determine an integral of the type

$$Z_0(r)=\left(\frac{a}{2\pi}\right)^2\iint\limits_{\text{period}} d\omega\frac{\exp\{i\omega r\}}{\mu_0+v_0\omega^2}\,. \tag{18}$$

In this case we integrate over a square area of the reciprocal lattice, so that $Z_0(\mathbf{r})$ satisfies the following partial differential equation

$$\left[\mu_0-v_0\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)\right]Z_0(r)=\left(\frac{a}{\pi}\right)^2\frac{\sin\frac{\pi}{a}x}{x}\frac{\sin\frac{\pi}{a}y}{y}\,. \tag{19}$$

Instead of evaluating the integral in (18), we now solve this equation with the aid of the Green's function with cylindrical symmetry. In the course of the solution introduced, for example, in Chapter 7 of [5], we obtain

$$Z_0(r)=\frac{a}{2\pi^3 v_0}\iint\limits_{-\infty}^{\infty} dx'dy'K_0\left(\varkappa\sqrt{(x-x')^2+(y-y')^2}\right)\frac{\sin\frac{\pi}{a}x'}{x'}\,\frac{\sin\frac{\pi}{a}y'}{y'}\,, \tag{20}$$

where $K_0(z)$ is the MacDonald function of zeroth order.

In this case we use the relation $\varkappa^2=\frac{\mu_0}{v_0}$, which is valid only for small $\varkappa^2$, in equation (5). It is always the case that $v_j>0$, and for inactive media, also $\mu_0>0$. Furthermore, if $|\mathbf{r}|$ is large, then we may substitute the function $\frac{\sin pz}{z}\simeq\pi\delta(z)$ into expression (20), so that

$$Z_0(r)\simeq\frac{a^2}{2\pi v_0}K_0(\varkappa|r|). \tag{21}$$

If we substitute (21), in accordance with (13) and (17), into (15), then for $|\mathbf{k}|\to\infty$ we obtain the following result:

$$N_{ac}(ka)\simeq N(0)\left\{\left(\frac{a}{2\pi}\right)^2\iint\limits_{\text{period}} d\omega\frac{1-F_1(\omega)}{1-F_0(\omega)}\times I_0(\varkappa|k|a)-\frac{a^2}{2\pi v_0}\frac{q_{00}}{q_{01}}\times(\mu_1-v_1\varkappa^2)K_0(\varkappa|k|a)\right\} \tag{22}$$

If we write the continuous argument $\mathbf{r}$ in place of $\mathbf{k}a$ in this expression, then a limiting formula is obtained for the distribution of neutrons in a homogeneous medium. Therefore, expression (22) may be employed in determining the constant for a heterogeneous medium in the case of its homogenization. Formula (22) is asymptotically valid; in the immediate neighborhood of the perturbation formula (15) is valid, which differs somewhat from (22) (the "nonasymptotic correction").

2. Active medium

It is not possible to use Feinberg's method to solve equation (1) for an active medium, since in this case for the given ω^2 the denominator in (14) vanishes. Similar difficulties are met and overcome in the quantum theory of fields.

One may proceed in an analogous manner also in the case of active media for the case examined, but the methods and mathematical apparatus used, for example, in [2], are more convenient.

We denote the amplitude of the Fourier integral (3) by

$$G_j(\omega) = \left(\frac{a}{2\pi}\right)^2 \frac{1}{q_{0j}} \frac{\eta_j \exp\{-\omega^2\tau\} - 1}{1 + L^2\omega^2}, \quad (j = 0, 1),$$
$$G(\omega) = G_1(\omega) - G_0(\omega). \tag{23}$$

Then one may show that, solving equation (1) for an active medium formed by blocks 0, we obtain the expression

$$N(\mathbf{k}a) = \{N_1(\mathbf{k}a) + CN_2(\mathbf{k}a)\}N(0), \tag{24}$$

in which

$$N_1(\mathbf{r}) = -\frac{i}{2}\int\limits_{-\infty}^{\infty} dx \frac{x}{|x|} \iint\limits_{-\infty}^{\infty} d\omega \exp\{i\mathbf{r}\omega\} \times G(\omega) \exp\{ix[1 - F_0(\omega)]\}, \tag{25a}$$

$$N_2(\mathbf{r}) = \frac{1}{2\pi}\int\limits_{-\infty}^{\infty} dx \iint\limits_{-\infty}^{\infty} d\omega \exp\{i\mathbf{r}\omega\} \times G(\omega) \exp\{ix[1 - F_0(\omega)]\}. \tag{25b}$$

If one considers $\mathbf{k} = 0$ in (24), then one may determine the value of the constant C

$$C = \frac{1 - N_1(0)}{N_2(0)}. \tag{25c}$$

The function $F_0(\omega)$ is determined in the same way as in (13c).

We shall verify this assertion. We set expression (25a) into expression $N(\mathbf{k}a) - \sum\limits_{\mathbf{k}'} H_0(|\mathbf{k} - \mathbf{k}'|a) N(\mathbf{k}'a)$.

After a few transformations we obtain

$$-\frac{i}{2}\int\limits_{-\infty}^{\infty} dx \frac{x}{|x|} \iint\limits_{-\infty}^{\infty} d\omega \exp\{ia\mathbf{k}\omega\} G(\omega)[1 - F_0(\omega)] \exp\{ix[1 - F_0(\omega)]\} =$$
$$= -\frac{i}{2}\int\limits_{-\infty}^{\infty} dx \frac{x}{|x|} \iint\limits_{-\infty}^{\infty} d\omega \exp\{ia\mathbf{k}\omega\} G(\omega)(-i)\frac{d}{dx} \exp\{ix[1 - F_0(\omega)]\} =$$
$$= \lim_{k\to\infty}\left(-\frac{1}{2}\right)\iint\limits_{-\infty}^{\infty} d\omega \exp\{ia\mathbf{k}\omega\} G(\omega)\{2\cos[k(1 - F_0(\omega))] - 2\} =$$
$$= \iint\limits_{-\infty}^{\infty} d\omega \exp\{ia\mathbf{k}\omega\} G(\omega) = h(a|\mathbf{k}|). \tag{26}$$

The next to last relation follows from Riemann's lemma, and the last, from definitions (23), (2), and (3). Treating (25b) in an analogous manner, we obtain zero instead of (26). This means that expression (24) with the constant C from (25c) is a solution to equation (1) for $\mathbf{k} = 0$.

Formulas (25a) and (25b) may be represented in a different form. Since $[1 - F_0(\omega)]$ in accordance with definition (13b) is a periodic function of the vector in the reciprocal lattice (such as $\exp\{ia\,\mathbf{k}\omega\}$), it follows that it does not change under substitutions of the type $\omega' = \omega + \mathbf{n}\frac{2\pi}{a}$, where $\mathbf{n}$ is a vector whose components are whole numbers. Therefore, the integration with respect to ω in expressions (25a) and (25b) may be replaced by integration over the area of a single cell of the reciprocal lattice. In such a transformation there appears a sum $\sum\limits_{n} G\left(\omega + n\frac{2\pi}{a}\right)$ in place of the function $G(\omega)$. With accuracy up to a coefficient $(\frac{a}{2\pi})^2$ one obtains the same expression $f(\omega)$ which is obtained from formulas (13c) and (6). As a consequence one may write

$$N_1(ka) = -\frac{i}{2}\int_{-\infty}^{\infty} dx \frac{x}{|x|} \iint_{\text{period}} d\omega \left(\frac{a}{2\pi}\right)^2 \exp\{iak\omega + ix[1 - F_0(\omega)]\} f(\omega), \tag{27a}$$

$$N_2(ka) = \frac{1}{2\pi}\int_{-\infty}^{\infty} dx \iint_{\text{period}} d\omega \left(\frac{a}{2\pi}\right)^2 \exp\{iak\omega + ix[1 - F_0(\omega)]\} f(\omega). \tag{27b}$$

Expressions (25) and (27) are to a certain extent formal. Their physical and mathematical content is easily exhibited in the same manner as was done in the preceding portion of this paper for large $|\mathbf{r}|$ or $|\mathbf{k}|$. We indicate this for formulas (25). If $\mathbf{r} \to \infty$, then the region of intergration in formulas (25) will be significant only for small ω^2. In this case from (16), after the substitution $x \to q_{00}(1 + L^2\omega^2)x$ we obtain

$$N_{1,\text{ac}}(r) = -\frac{i}{2} q_{00} \int_{-\infty}^{\infty} dx \frac{x}{|x|} \iint_{-\infty}^{\infty} d\omega \exp\{ir\omega + ix(\mu_0 + v_0\omega^2)\} G(\omega) [1 + L^2\omega^2], \tag{28a}$$

$$N_{2,\text{ac}}(r) = \frac{1}{2\pi} q_{00} \int_{-\infty}^{\infty} dx \iint_{-\infty}^{\infty} d\omega \exp\{ir\omega + ix(\mu_0 + v_0\omega^2)\} G(\omega) [1 + L^2\omega^2]. \tag{28b}$$

The integrals may be calculated as in [2] (see the Appendix). If one bears (23) in mind, i.e.

$$G_j(\omega) = \Gamma_j(\omega^2),\ G(\omega) = \Gamma(\omega^2) = \Gamma_1(\omega^2) - \Gamma_0(\omega^2), \tag{29}$$

then the results obtained in the Appendix may be generalized:

$$N_{1,\text{ac}}(r) = -\frac{\pi^2 q_{00}}{v_0}\left(1 - \frac{\mu_0}{v_0}L^2\right)\Gamma\left(-\frac{\mu_0}{v_0}\right) Im\left[H_0^{(1)}\left(|r|\left(-\frac{\mu_0}{v_0}\right)^{\frac{1}{2}}\right)\right] -$$
$$- \frac{a^2 q_{00}}{4\pi v_0}\left(\frac{\eta_1}{q_{01}} - \frac{\eta_0}{q_{00}}\right)\exp\left\{\frac{\mu_0}{v_0}\tau\right\}\int_0^{\tau}\frac{dz}{z}\exp\left\{-\frac{\mu_0}{v_0}z - \frac{r^2}{4z}\right\}, \tag{30a}$$

$$N_{2,\text{ac}}(r) = \frac{\pi q_{00}}{v_0}\left(1 - \frac{\mu_0}{v_0}L^2\right)\Gamma\left(-\frac{\mu_0}{v_0}\right) Re\, H_0^{(1)}\left(|r|\left(-\frac{\mu_0}{v_0}\right)^{\frac{1}{2}}\right), \tag{30b}$$

where $H_0^{(1)}(z)$ – is Hankel's function of the first kind and zeroth order. For large $|\mathbf{r}|$ and small $\left|\frac{\mu_0}{v_0}\right|\tau$ the second terms in (30a) may be neglected. For small values of $\left|\frac{\mu_0}{v_0}\right|$ the homogenization conditions for the lattice are fulfilled and the Laplacian $\varkappa^2 = -(\mu_0/v_0)$ (for active media $\mu_0 < 0$). In this case we again may compare the results obtained with the results for active homogeneous media into which a perturbing rod is inserted. As is known,

$$\begin{gathered} Im H_0^{(1)}\left(|z|(-\lambda)^{\frac{1}{2}}\right) = N_0\left(|z|(-\lambda)^{\frac{1}{2}}\right) \\ \text{for } \lambda < 0, \\ Im H_0^{(1)}\left(|z|(-\lambda)^{\frac{1}{2}}\right) = -\frac{2}{\pi} K_0\left(|z|\lambda^{\frac{1}{2}}\right) \\ \text{for } \lambda > 0, \\ Re H_0^{(1)}\left(|z|(-\lambda)^{\frac{1}{2}}\right) = I_0\left(|z|(-\lambda)^{\frac{1}{2}}\right) \\ \text{for } \lambda < 0, \\ Re H_0^{(1)}\left(|z|(-\lambda)^{\frac{1}{2}}\right) = 0 \\ \text{for } \lambda > 0, \end{gathered} \tag{31}$$

where $I_0(z)$ and $N_0(z)$ are Bessel functions of the first and second kind of zeroth order. For active media ($\lambda < 0$) we obtain the same dependence as was obtained for homogeneous media, and therefore, on the basis of formulas (30), (24), and (25c) we may determine the corresponding constants for heterogeneous media under the conditions of its homogenization.

In deriving formula (30) we proceed from (25). We may obtain an analogous result proceeding from (27). Since in these formulas for large $|\mathbf{k}|$ the region of large ω^2 barely plays a role, the integration with respect to ω_1 and ω_2 may be extended from a single cell of the reciprocal lattice to the entire region $(-\infty, \infty)$. Thus one again obtains formulas analogous to (30), but with these changes: in (30) the function $\Gamma[-(\mu_0/\nu_0)]$ is replaced by

$$\dot{\Gamma}\left(-\frac{\mu_0}{v_0}\right) \to \frac{a^2}{(2\pi)^2}\Phi\left(-\frac{\mu_0}{v_0}\right), \tag{32a}$$

where, as in (29), for small values of ω^2 the following notation is introduced, on the basis of (5):

$$F_j(\omega) = \Phi_j(\omega^2) = \frac{\eta_j \exp\{-\omega^2\tau\} - 1}{q_{0j}(1+L^2\omega^2)} - \frac{q_{1j}}{q_{0j}},\ \Phi(\omega^2) = f(\omega) = \Phi_1(\omega^2) - \Phi_0(\omega^2). \tag{32b}$$

The function $(\frac{a}{2\pi})^2\ \Phi_j(\omega^2)$ differs from $\Gamma_j(\omega^2)$ by the terms $\frac{q_{1j}}{q_{0j}}$ corresponding to the external block effect connected with the heterogeneous lattice structure. The loss of the corresponding terms associated with the external block-effect in formulas (30), (29), and (23), is explained by the fact that in the transition from (25) to (28) the periodic function $1-F_0(\omega)$ is replaced by the function $\frac{\mu_0+\nu_0\omega^2}{q_{00}(1+L^2\omega^2)}$ nonperiodic in ω, and the transformation analogous to (27) does not lead to the appearance in (28) of the function $f(\omega)$, expressing the lattice structure. However in many cases the block effect may be neglected, since $q_{1j} \ll q_{0j}$.

The following comparison also testifies to the fact that expression (30) with the substitution (32) is a better approximation than (30) with the factor $\Gamma[-(\mu_0/\nu_0)]$ from (29). From relation (31) it is clear that formula (30a) is valid for inactive media also. The comparison of (30a) and (24) with formula (22), derived another way for inactive media, shows that the external block-effect is not considered in actuality in (30a). In this it is necessary only to recall that $\Phi_0[-(\mu_0/\nu_0)] = 1$.

3. Critical medium

We shall examine this case only briefly. Calculations using the diffusive approximation for a homogeneous medium show that the density of thermal neutrons is described by the formula

$$N(\boldsymbol{r}) = C\left(1 + \frac{\gamma_t}{2\pi D}\lg\frac{|\boldsymbol{r}|}{\varrho}\right), \tag{33}$$

in which C is the density on the surface of the perturbing block, γ_t – the constant in [1], ρ the radius, and D the diffusion coefficient of the medium. Formula (33) may be obtained also by a limiting process from the noncritical case (for example, from an inactive medium) to a critical (infinite) homogeneous medium in which a perturbing block is introduced.

One may derive the formula for perturbation in a critical lattice in an analogous manner. We take, for example, the inactive medium which we considered in the first section. In regions at distances sufficiently far from the perturbation, formula (22) is valid. In the limit $\varkappa \to 0$ we have $I_0(\varkappa|k|a) \simeq 1$ and $K_0(\varkappa|k|a) \simeq -\left\{\lg\frac{\varkappa|k|a}{2} + \gamma\right\}$, where γ is Euler's constant. In doing this, it is sufficient to investigate the behavior of the integrals (15) for small values of ω^2 in order to avoid a divergence of the type $\lg\varkappa$ as $\varkappa \to 0$ in (22). For given $|\mathbf{k}|$ it is always possible to choose a sufficiently small value of $\beta(|\mathbf{k}|)$ such that in a circle of radius β one may limit oneself in the second term of expression (15) to the first term of the Taylor series expansion in ω (or $\varkappa \to 0$). Then one may write

$$\begin{aligned} N(ka) = N(0)\ &\left\{\left(\frac{a}{2\pi}\right)^2 \int\limits_0^{\beta(|k|)} d\omega\omega \int\limits_{-\pi}^{\pi} d\varphi\, \frac{(\mu_1+v_1\omega^2)\left[\ 1+\frac{\mu_0}{4v_0}(ka)^2\right) - \left(1+i\omega ka - \frac{(\omega ka)^2}{2}\right)\right]}{\mu_0+v_0\omega^2} + \right. \\ &\left. + \ldots\right\} = N(0)\left\{\left(\frac{a}{2\pi}\right)^2 \int\limits_0^{\beta} 2\pi d\omega\omega\, \frac{(ka)^2}{4v_0}(\mu_1+v_1\omega^2) + \ldots\right\} = \\ &= N(0)\left\{\frac{(ka)^2 v_1 (a+\beta)^2}{16\pi v_0}\left(\frac{\mu_1}{v_1}+\frac{\beta^2}{2}\right) + \ldots\right\}. \end{aligned} \tag{34}$$

In this expansion that part which may lead to a divergence for $\varkappa = \sqrt{\frac{\mu_0}{v_0}} \to 0$ is separated out. However, from (34) it is clear that the entire expression (15) tends in the limit $\varkappa \to 0$ to a finite value, so that expression (33) will be finite. In an analogous manner one may effect the transition from formulas (24) and (25) to formula (33).

Consequently if we set $\mathbf{k}a = \mathbf{r}$, we may write the following formula on the basis of (22) and the preceding considerations:

$$N_{\text{ac}}(\boldsymbol{r}) = N(0) \lim_{\mu_0 \to 0} \left\{ \left(\frac{a}{2\pi}\right)^2 \iint\limits_{\text{period}} d\omega \frac{1-F_1(\omega)}{1-F_0(\omega)} + \frac{a^2 q_{00}\mu_1}{2\pi q_{01} v_0} \left(\lg \frac{\varkappa |\boldsymbol{r}|}{2} + \gamma \right) \right\}, \tag{35}$$

in which it should be kept in mind that $\varkappa^2 = (\mu_0/v_0)$ and always $v_0 > 0$. We now express $\lg\varkappa$:

$$\lg \varkappa = \lg \sqrt{\frac{\mu_0}{v_0} + \left(\frac{\pi}{a}\right)^2} - \frac{1}{2\pi} \iint\limits_{K} \frac{v_0 \, d\omega}{\mu_0 + v_0 \omega^2}, \tag{36}$$

where the integration is taken over the area of the circle K with radius $\frac{\pi}{a}$.

Then the constant term in braces in (35) may take on the following form:

$$A = \left(\frac{a}{2\pi}\right)^2 \lim_{\mu_0 \to 0} \iint\limits_{K} d\omega \left\{ \frac{1-F_1(\omega)}{1-F_0(\omega)} - \frac{q_{00}}{q_{01}} \frac{\mu_1}{\mu_0 + v_0\omega^2} \right\} + \left(\frac{a}{2\pi}\right)^2 \iint\limits_{z,\, \mu_0 = 0} d\omega \frac{1-F_1(\omega)}{1-F_0(\omega)} + \frac{a^2 q_{00}\mu_1}{2\pi q_{01} v_0} \left[\lg \frac{\pi}{2a} + \gamma \right]. \tag{37}$$

In the first integral two terms are united in such a manner that, firstly, the integral exists in the limit $\mu_0 \to 0$, and secondly, it may be used for practical (numerical) calculations. The existence of the limit $\mu_0 \to 0$ of the integral follows immediately from the expression (16) for the function $1 - F_j(\omega)$ for small ω. In the second integral we set $\mu_0 = 0$, so that the symbol Z at the integral sign signifies that the integration is taken over the area external to the circle with radius $\frac{\pi}{a}$ and inside the square with sides $\frac{2\pi}{a}$ (and with the same center), i.e., outside the "danger" zone of the integral from the point of view of the limit $\mu_0 = 0$.

We further denote the constant in the braces (35) by

$$B = \frac{a^2 q_{00}\mu_1}{2\pi q_{01} v_0}, \tag{38}$$

so that

$$N_{\text{ac}}(\boldsymbol{r}) = N(0)\{A + B \lg |\boldsymbol{r}|\}. \tag{39}$$

This expression may be used for determining the homogenization constants in formula (33). If we set C = N(0) (based on the fact that both quantities are densities of neutrons on the surface of the corresponding perturbing blocks), then by comparing (33) and (37) we obtain

$$\frac{\gamma_t}{2\pi D} = B, \quad \varrho = \exp\left\{\frac{1-A}{B}\right\}. \tag{40}$$

The first relation determines the effective value of the thermal constant of the perturbing block. However, it is still necessary to determine the effective diffusion coefficient D. From (38) it follows that $\gamma_t = 0$, if $\mu_1 = 0$. (This equation is the criticality condition for an infinite lattice consisting of blocks of the first type). Then, according to (39) $N_{\text{ac}}(\mathbf{r}) = \text{const}$.

The second relation determines the effective radius of the perturbing cylindrical block under the conditions that on the cylindrical surface with radius ρ $C = N(0)$.

From the point of view of practical applications, it is more convenient to introduce the effective radius of the "opaque" block (in the lattice), i.e., the radius on which the density of neutrons (39) or (33) is zero. If we denote it by ρ_{eff}, then from the fact that (39) is equal to zero it follows that

$$\rho_{\text{eff}} = \exp\left\{-\frac{A}{B}\right\} = \rho \exp\left\{-\frac{1}{B}\right\}. \tag{41}$$

Obviously this does not depend on making the equation C = N(0) more accurate.

CONCLUSION

The problem of replacing one block in a regular square lattice by a block with different properties was investigated. In this two different methods were applied for the cases of a supercritical or subcritical infinite lattice. These methods supplement and control each other. In using the formulas obtained for practical aims much more lengthy numerical calculations are sometimes needed. The results obtained may be extended also to other types of lattices.

The author takes this opportunity to thank A. D. Galanin for fruitful discussions on the theme of this paper.

APPENDIX

Corresponding to formulas (28) and (23) it is necessary to find integrals of the following form ($|r| \to \infty$):

$$V_1(\tau)=\int_{-\infty}^{\infty} dx \frac{x}{|x|} \exp\{ix\mu_0\} \int\int_{-\infty}^{\infty} d\omega \exp\{ixv_0\omega^2+ir\omega-\tau\omega^2\}, \tag{A. 1}$$

$$V_2(\tau)=\int_{-\infty}^{\infty} dx \exp\{ix\mu_0\} \int\int_{-\infty}^{\infty} d\omega \exp\{ixv_0\omega^2+ir\omega-\tau\omega^2\} \tag{A. 2}$$

for τ equal to the square of the slowing length in the slowing medium, as well as for $\tau = 0$.

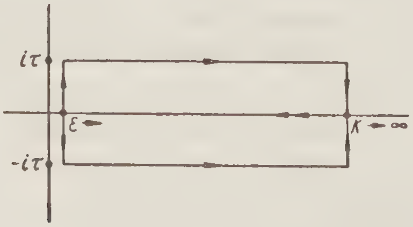
We calculate first the integral $V_1(\tau)$. We introduce a new variable of integration according to the substitution $\varkappa \to \frac{x}{v_0}$ $(v_0 > 0)$, and in the argument of the second exponential function in (A. 1) we complete the square

$$V_1(\tau)=\frac{1}{v_0}\int_{-\infty}^{\infty} dx \frac{x}{|x|} \exp\left\{ix\frac{\mu_0}{v_0}\right\} \int\int_{-\infty}^{\infty} d\omega \exp\left\{i(x+i\tau)\left[\left(\omega+\frac{r}{2(x+i\tau)}\right)^2-\frac{r}{4(x+i\tau)^2}\right]\right\}. \tag{A. 3}$$

The integrals with respect to ω_1 and ω_2 are integrals of the Laplace type. Limiting oneself to the integration with respect to x in the interval (0, ∞), one obtains

$$V_1(\tau)=\frac{i\pi}{v_0}\exp\left\{\frac{\mu_0}{v_0}\tau\right\}\int_0^{\infty}\frac{dx}{x+i\tau}\exp\left\{i\frac{\mu_0}{v_0}(x+i\tau)-i\frac{r^2}{4(x+i\tau)}\right\}+\frac{i\pi}{v_0}\exp\left\{\frac{\mu_0}{v_0}\tau\right\}\int_0^{\infty}\frac{dx}{x-i\tau}\exp\times$$
$$\times\left\{-i\frac{\mu_0}{v_0}(x-i\tau)+i\frac{r^2}{4(x-i\tau)}\right\}. \tag{A.4}$$

Both of the latter expressions may be considered as integrals with respect to a complex variable, i.e., with respect to $r=x+i\tau$ and $r=x-i\tau$, and in the limit the range of integration becomes $(0+i\tau,\ \infty+i\tau)$ and $(0-i\tau,\ \infty-i\tau)$. The path of integration in the complex plane may be chosen as shown in the figure



Path of integration in calculating the right side of formula (A. 4).

On the basis of Cauchy's therorem we obtain the following result:

$$V_1(\tau)=\frac{2\pi i}{v_0}\exp\left\{\frac{\mu_0}{v_0}\tau\right\}\left[\int_0^\infty\frac{dz}{z}\cos\left[-\frac{\mu_0}{v_0}z+\frac{z^2}{4z}\right]-\int_0^\tau\frac{dz}{z}\exp\left\{-\frac{\mu_0}{v_0}z-\frac{r^2}{4z}\right\}\right]. \qquad (A.\ 5)$$

Introducing Hankel's function of the first kind of zeroth order, we may write

$$V_1(\tau)=-\frac{2\pi^2 i}{v_0}\exp\left\{\frac{\mu_0}{v_0}\tau\right\}H_0^{(1)}\left(|r|\left(-\frac{\mu_0}{v_0}\right)^{\frac{1}{2}}\right)-\frac{2\pi i}{v_0}\exp\left\{\frac{\mu_0}{v_0}\tau\right\}\int_0^\tau\frac{dz}{z}\exp\left\{-\frac{\mu_0}{v_0}z+\frac{r^2}{4z}\right\}. \qquad (A.\ 6)$$

The value of $V_2(\tau)$, defined by (A. 2), may be calculated in the same way. However, due to the factor $\frac{x}{|x|}$ in (A. 1), the second term in (A.4) will have a minus sign, so that in (A. 5) in the first term a sine function with factor (-i) will appear instead of a cosine, and the second term will in general drop out. But then

$$V_2(\tau)=\frac{2\pi^2}{v_0}\exp\left\{\frac{\mu_0}{v_0}\tau\right\}\mathrm{Re}\,H_0^{(1)}\left(|r|\left(-\frac{\mu_0}{v_0}\right)^{\frac{1}{2}}\right). \qquad (A.\ 7)$$

We determine now the integrals (similar to (A. 1) and (A. 2) in which the function $\exp\{-\tau\omega^2\}$ is replaced by $(1+L^2\omega^2)$. Detailed calculations show that they may be obtained by replacing, in (A. 6) and (A. 7), $\exp\left\{\frac{\mu_0}{v_0}\tau\right\}$ by the function $\left(1-\frac{\mu_0}{v_0}L^2\right)$ and omitting the second terms in (A. 6) ($|r|$ large).

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

CRITERIA FOR DETERMINING INSTABILITY DUE TO TEMPERATURE CHANGES DURING TRANSIENT REACTOR OPERATION*

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In this paper we study the kinetics of uranium-graphite reactors of the Calder-Hall type taking into account the temperature coefficient of reactivity and its changes during the burning up of the fuel. We obtain the conditions of instability for the reactor. We show that in reactors of the Calder-Hall type when the fuel is burnt up 3000 Mwatt-day/m the minimum positive period of the reactor must be not less than 170 seconds.

INTRODUCTION

A negative temperature coefficient of reactivity in a nuclear reactor is a strong stabilizing factor which hinders the deviation of the reactor power from the stable (equilibrium) level during various disturbances in normal operation. The majority of reactors have negative temperature coefficients. However, we know that in a gas-cooled, thermal neutron uranium-graphite reactor which uses uranium fuel the total temperature coefficient becomes positive after the reactor has been in operation for some time (~225 Mwatts-day/m for a reactor of the Calder-Hall type) [1]. This destroys the stable operation of the reactor and if the positive reactor period which is caused by the positive temperature coefficient is not large enough then the control of such a reactor may prove to be difficult or even impossible. According to the published data this period is very large for the Calder-Hall reactor (~3 minutes). However, the authors have decided to write this paper to determine the nature and magnitude of these instabilities.

Inasmuch as in a thermal neutron heterogeneous reactor the temperature of the uranium changes much more rapidly than the temperature of the moderator (due to the low heat capacity of the fuel) it is customary to divide the temperature coefficient of reactivity into two parts - the temperature coefficient of uranium (α_U) - and the slowly changing portion - the temperature coefficient of the moderator (α_m). The time constants associated with the first and second parts are 10 sec. and 10 minutes respectively. Within the time which, due to the bombardment of the fuel, the coefficient α_U remains practically constant ($\sim -2 \times 10^{-5}$), the coefficient α_m increases. This is due to the isotopic composition of the fuel, especially due to the accumulation of Pu^{239} whose fission cross section has a resonant point ~0.3 electron volts. In reactors using enriched uranium the increase in α_m cannot be significant since the change in the fuel composition due to the accumulation of plutonium is relatively small. We can also say the same about reactors having liquid moderators where the value of α_m is basically due to the density of the latter and where we cannot expect any basic change in the latter. However, in heterogeneous reactors with solid moderators which use natural uranium as the reactor fuel α_m can become very large and positive and this leads to additional difficulties in the regulation of the reactor and in insuring safe reactor operation. Further on in the paper we will obtain instability criteria which take into account the space distribution of the neutron flux as a function of the temperature coefficients and the temperatures for the corresponding stable conditions. We also make an estimate of the smallest possible positive period for reactors of the Calder-Hall type which can be obtained for various values of α_m.

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*Translated from an English paper obtained from India.

We assumed that the number and temperature of the heat carriers entering the reactor was constant and that the temperature distribution during the transitional processes changes in the same manner throughout the reactor. We neglect second order terms such as, for example $\Phi'T'$ and also the effect of xenon poisoning.

DESIGNATIONS

Φ - total neutron flux
Φ_i - delayed neutron flux for the i-th group
τ_0 - neutron lifetime in an infinite medium
M^2 - migration area
k_{00} - instantaneous value of the coefficient of multiplication
β_i - fraction of delayed neutrons in the i-th group
p - resonance escape probability
Σ_a - macroscopic absorption cross section
λ_i - decay constant, i-th group of nuclear sources of delayed neutrons
C_i - concentration of the nuclear sources of delayed neutrons in the i-th group per unit volume
B_0^2 - material parameters of the reactor in the stable state

α - temperature coefficient of reactivity (1/°C)
T - temperature
H - total heat emission per unit length of fuel canal per second
f_H - heat emission fraction for the fuel
P - perimeter
h - coefficient of heat transfer
ρ - density
c - specific heat capacity
s - area of transverse cross section
v - heat carrier velocity
l - length of fuel canal

The indices * and ' refer to the stationary (stable) and perturbed state respectively. The indices U, m, c and 1,2 refer to the uranium, moderator, heat carrier, the heat carrier at the surface of the uranium and the heat carrier at the moderator surface, respectively.

Neutron Kinetics

In the diffusion approximation the dependence of the neutron flux Φ upon the time for a reactor which is in the unstable state is given by the following equation

$$\tau_0\left(\frac{\partial\Phi}{\partial t}+\sum_i\frac{\partial\Phi_i}{\partial t}\right)=M^2\nabla^2\Phi+(k_\infty-1)\,\Phi;\quad \tau_0\frac{\partial\Phi_i}{\partial t}=-\lambda_i\tau_0\Phi_i+k_\infty\beta_i\Phi, \tag{1}$$

where

$$\Phi_i=\frac{p}{\Sigma_a}\,\frac{C_i}{\tau_0};\qquad \beta=\sum_i\beta_i.$$

For a reactor in the stable state these equations can be reduced to the following:

$$M^2\nabla^2\Phi^*+(k^*_\infty-1)\,\Phi^*=0,\ \text{i.e.}\quad M^2\,(\nabla^2+B_0^2)\,\Phi^*=0;\quad -\lambda_i\tau_0\Phi^*_i+k^*_\infty\beta_i\Phi^*=0. \tag{1a}$$

We will write the coefficient k_∞ in the following form

$$k_\infty=k^*_\infty+\alpha_U T'_U+\alpha_m T'_m. \tag{2}$$

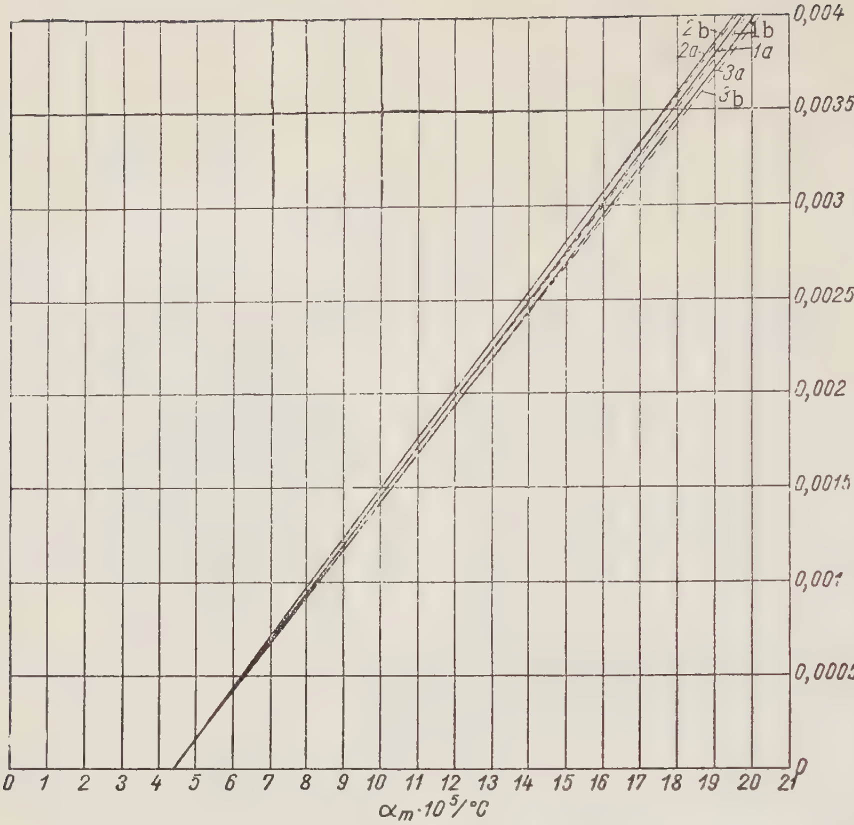
Temperature Changes

The heat balance equations may be written as shown below for the case which we are studying:

$$\begin{gathered}\varrho_U C_U S_U\frac{dT_U}{dt}=f_H H-\mathcal{P}_1 h_1\,(T_U-T_c);\quad \varrho_m C_m S_m\frac{dT_m}{dt}=(1-f_H)\,H-\mathcal{P}_2 h_2\,(T_m-T_c);\\ \varrho_c C_c S_c\left[\frac{dT_c}{dt}+\frac{v}{l}\,(T_{c\,\text{out}}-T_{c\,\text{in}})\right]=\mathcal{P}_1 h_1\,(T_U-T_c)+\mathcal{P}_2 h_2\,(T_m-T_c).\end{gathered} \tag{3}$$

We will take as the zero point of our temperature scale the temperature of the heat carriers when they enter the reactor $T_{c\,\text{in}}$. We assume that $T_{c\,\text{in}}$ is constant. We will assume further that $T_{c\,\text{out}} = 2T_c$, this relation holds true in the steady state [3]. We also wish to introduce the following designations:

$$\begin{gathered}\chi=\varrho CS;\quad \gamma_U=\frac{\mathcal{P}_1 h_1}{\chi_U};\quad \gamma_m=\frac{\mathcal{P}_2 h_2}{\chi_m};\quad \gamma_c=\frac{2v}{l};\\ \gamma_{Uc}=\frac{\mathcal{P}_1 h_1}{\chi_c};\quad \gamma_{mc}=\frac{\mathcal{P}_2 h_2}{\chi_c}.\end{gathered} \tag{3aa}$$



Plot of ω_0 as a Function of α_m: 1a - exact solution; 2a - approximation $\chi_m \frac{\partial T_m}{\partial t} = 0$; 3a - approximation $\chi_U \frac{\partial T_U}{\partial t} = 0$ or $\chi_m \frac{\partial T_m}{\partial t} = \chi_U \frac{\partial T_U}{\partial t} = 0$. Curves 1b, 2b and 3b were obtained using calculation which assumed one effective group of neutrons.

Then the system of equations (3) can be written in the form

$$\left.\begin{aligned} \frac{dT_U}{dt} = \frac{f_H}{\chi_U} H - \gamma_U (T_U - T_c); \quad \frac{dT_m}{dt} = \frac{(1 - f_H)}{\chi_m} H - \gamma_m (T_m - T_c); \\ \frac{dT_c}{dt} + \gamma_c T_c = \gamma_{Uc} (T_U - T_c) + \\ + \gamma_{mc} (T_m - T_c). \end{aligned}\right\} \qquad (3a)$$

The corresponding equations for the stable state may be written in the form

$$T_U^* = T_c^* + \frac{f_H H^*}{\chi_U \gamma_U}; \quad T_m^* = T_c^* + \frac{(1 - f_H)}{\chi_m \gamma_m} H^*; T_c^* = \frac{H^*}{\gamma_c} \left[\frac{f_H}{\chi_U} \frac{\gamma_{Uc}}{\gamma_U} + \frac{(1 - f_H)}{\chi_m} \frac{\gamma_{mc}}{\gamma_m} \right]. \qquad (3b)$$

General Kinetic Equations

In order to study the transient operation of the system, which was caused by changes in the temperature and power of the reactor, we solved equations (1), (2) and (3a) simultaneously.

The coefficient α_m changed with the degree of bombardment of the fuel. Since the bombardment of the fuel is not uniform in the active zone we will use the effective value of α_m; this value depends upon the value chosen for the fuel cycle.

Let us introduce the designations $T = T^* + T'$; $\Phi = \Phi^* + \Phi'$; $\Phi_i = \Phi_i^* + \Phi_i'$ in equations (1) and (3a). Using equations (1a), (2) and (3b) and bearing in mind that the heat emission is proportional to the flux we get

$$\left.\begin{aligned} \tau_0 \left(\frac{\partial \Phi'}{\partial t} + \sum_i \frac{\partial \Phi_i'}{\partial t} \right) = M^2 (\nabla^2 + B_0^2) \Phi' + (\alpha_U T_U' + \alpha_m T_m') \Phi^*; \quad \tau_0 \frac{\partial \Phi_i'}{\partial t} = - \lambda_i \tau_0 \Phi_i' + \\ + \beta_i \Phi^* (\alpha_U T_U' + \alpha_m T_m') + k_\infty^* \beta_i \Phi' \end{aligned}\right\} \qquad (1b)$$

and

$$\frac{\partial T'_U}{\partial t} = A\Phi' - \gamma_U (T'_U - T'_c); \quad \frac{\partial T'_m}{\partial t} = B\Phi' - \gamma_m (T'_m - T'_c); \quad \frac{\partial T'_c}{\partial t} + \gamma_c T'_c = \gamma_{Uc} (T'_U - T'_c) + \gamma_{mc}(T'_m - T'_c), \tag{3c}$$

$$A = \frac{\gamma_U (T^*_U - T^*_c)}{\Phi^*} = \frac{\gamma_U \Theta^*_U}{\Phi^*}; \quad B = \frac{\gamma_m (T^*_m - T^*_c)}{\Phi^*} = \frac{\gamma_m \Theta^*_m}{\Phi^*}. \tag{4}$$

We will solve the system of linear equations with the aid of the test functions:

$$\Phi' = a_s f_s e^{\omega_s t}; \quad \Phi'_i = b_{is} f_s e^{\omega_s t}; T'_U = C_s f_s e^{\omega_s t}; \quad T'_m = d_s f_s e^{\omega_s t}; T'_c = g_s f_s e^{\omega_s t}, \tag{5}$$

where the f_s, the space distribution harmonics are eigen-functions of the equations $(\nabla^2 + B_s^2) f_s = 0$, which turn into null at the extrapolation boundary of the reactor.

Substituting (5) into (1b) and (3c) and eliminating the constants a_s, b_{is}, c_s, and g_s we obtain the following equation for ω/ω_s:

$$(\omega_s + \gamma) \left[\omega_s \left(\tau_0 + k^*_\infty \sum_i \frac{\beta_i}{\lambda_i + \omega_s} \right) + M^2 \mu_s^2 \right] = K \left(1 - \sum_i \frac{\beta_i \omega_s}{\lambda_i + \omega_s} \right) (\omega_s + \gamma); \tag{6}$$

where

$$K = \frac{(\omega_s + \gamma) [\alpha_U \gamma_U \Theta^*_U (\omega_s + \gamma_m) + \alpha_m \gamma_m \Theta^*_m (\omega_s + \gamma_U)] - \gamma_U \gamma_m (\Theta^*_U - \Theta^*_m) (\alpha_m \gamma_{Uc} - \alpha_U \gamma_{mc})}{(\omega_s + \gamma) (\omega_s + \gamma_U) (\omega_s + \gamma_m) - \gamma_U \gamma_{Uc} (\omega_s + \gamma_m) - \gamma_m \gamma_{mc} (\omega_s + \gamma_U)};$$

$$\mu_s^2 = (B_s^2 - B_0^2); \quad \gamma = \gamma_c + \gamma_{Uc} + \gamma_{mc}. \tag{6a}$$

We readily see that $\omega_s = -\gamma$ is the root of equation (6). For the unstable case (i.e. where the real part of $\omega_s > 0$)

$$\left| \frac{\omega_s}{\lambda_i + \omega_s} \right| < 1, \text{ so that } \left| \sum_i \frac{\beta_i \omega_s}{\lambda_i + \omega_s} \right| < \beta \ll 1 \tag{6aa}$$

and equation (6) can be approximated (for roots for which $\omega_s = -\gamma$) by equation

$$\omega_s = \left(\tau_0 + k^*_\infty \sum_{i=1}^{6} \frac{\beta_i}{\omega_s + \lambda_i} \right) + M^2 \mu_s^2 = K, \tag{6b}$$

which is an equation of the 10-th degree in ω_s.

In order to obtain the critical condition which determines the appearance of instability, we will make use only of the limiting value of ω_s, namely we will let $\omega_s \to 0$ or $\frac{1}{\omega_s} \to \infty$. Therefore, we can neglect the value ω_s in comparison with the value λ_i and make use of the approximation $\frac{\beta_i}{\lambda_i + \omega_s} \cong \frac{\beta_i}{\lambda_i}$. If we let $\left(\tau_0 + k^*_\infty \sum_i \frac{\beta_i}{\lambda_i} \right) = l$ then equation (6b) takes the form of biquadratic equation

$$l\omega_s + M^2 \mu_s^2 = K. \tag{6c}$$

For values of γ, α and other parameters of Calder-Hall type reactors the conditions for which equation (6c) has no roots that have a positive real part are equivalent to the condition that the nonnegative term be constant, i.e.

$$\alpha_U \left[\left(1 - \frac{\gamma_{Uc}}{\gamma_c} \right) \Theta^*_U + \frac{\gamma_{mc}}{\gamma_c} \Theta^*_m \right] + + \alpha_m \left[\left(1 + \frac{\gamma_{mc}}{\gamma_c} \right) \Theta^*_m + \frac{\gamma_{Uc}}{\gamma_c} \Theta^*_U \right] \leqslant M^2 \mu_s^2. \tag{7}$$

This condition can be simplified if we make use of equation (3b):

$$\alpha_U T^*_U + \alpha_m T^*_m \leqslant M^2 \mu_s^2. \tag{7a}$$

Inasmuch as the temperatures T_U and T_m are measured by means of a scale for which $T_{c\ in}$ is the starting point, the expression which we have written (7a), really means

$$\alpha_U (T_U^* - T_c \text{ in}) + \alpha_m (T_m^* - T_c \text{ in}) \leqslant M^2\mu_s^2. \tag{8}$$

Equation (8) is the stability condition.*

Application of the Equations Derived in the Previous Section to Calder-Hall Type Reactors

1. We will substitute the following values:

$$T_U^* = 408° \text{ C}; \; T_m^* = 260° \text{ C}; \; T_{c \text{ in}} = 140° \text{ C}; \; \alpha_U = -2 \cdot 10^{-5}.$$

We then obtain, for the basic harmonic, $(\alpha_m)_{cr} = 4{,}47 \cdot 10^{-5}$. This value of α_m is reached after a burning up of 425 Mwatt · day/m [1]. For the first azimuthal harmonic the value of μ^2 is given by $\mu_1^2 = (8.9/a^2)$ (where $\underline{a}$ is the reactor radius). If a = 525cm and $M^2 = 1020 \text{ cm}^2$, then $M^2\mu_1^2 = 0.33$ and $(\alpha_m)cr = 32 \cdot 10^{-5}$.

2. For values of α_m exceeding the critical value the roots ω_s of equation (6b) that are of interest to us are either positive or have positive real parts. Using the available data for Calder-Hall type reactors we can get the following values for the constants entering into the system of equations (3b):

$H^* = 40.57$ cal/sec · cm
$\gamma c = 3.73 \text{ sec}^{-1}$
$\gamma m = 0.00145 \text{ sec}^{-1}$
$\gamma mc = 1.245 \text{ sec}^{-1}$
$\gamma U = 0.063 \text{ sec}^{-1}$

$\gamma Uc = 1.99 \text{ sec}^{-1}$
$f_H = 0.926$
$h_2 = 0.0044$ CGS units
$h_1 = 0.017$ CGS units

For an average heat carrier temperature of 238°C, $\Theta_m^* = 22° \text{ C}$ and $\Theta_U^* = 170° \text{ C}$.

Substituting the constants computed above into the first term of the first equation of system of equations (3) we see that this term $\left(\chi_U \frac{dT_U}{dt} \right)$ is much smaller than the other equation. We can therefore, assume that $\chi_U \frac{dT_U}{dt} \approx 0$ and, therefore, $-\chi_c \frac{dT_c}{dt} \approx 0.$.

In addition the reactor periods for larger values of α_m, which are the values which occur in actual reactor operation, are large in comparison with the maximum lifetime of the delayed neutrons. Therefore, we may use the single-group approximation for the delayed neutrons.

Using the above indicated constants and the data regarding the delayed neutrons obtained from [5] we found the exact solution of equation (6b) for the maximum positive value of ω_0, i.e. for the basic harmonics. In addition we obtained the various approximate solutions indicated in the text. The results of all solutions are given in the figure, and they confirm the usefulness of the approximate methods. We wish to point out that the double time $T_0 \left(= \frac{\ln 2}{\omega_0} \right)$ used in the first approximation is a function which is inversely proportional to α_m.

DISCUSSION OF RESULTS

When a reactor of the Calder-Hall type has been burnt up to the state 3000 Mwatt · day/m, which at the present time is the upper limit for one load of fuel, the coefficient α_m should not exceed $20 \cdot 10^{-5}$ [2]. As we can see from the figure the minimum positive reactor period that is reached for such values of α_m corresponds to a double time of the order of ~ 170 sec. Therefore, such a disturbance does not lead to especial difficulties in the control of the reactor. Disturbances in the space harmonics of a higher order arise for high values of α_m and they will lead to correspondingly longer periods for a given value of α_m. The problems associated with the space dependence of disturbances in these are discussed in [6].

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*If our study were to include the poisoning effect of xenon then equation (8) must be written in the form [4]

$$\alpha_U (T_U^* - T_c \text{ in}) + \alpha_m (T_U^* - T_c \text{in}) + \frac{A\chi_s^* \lambda_s}{\lambda_s + \lambda_{Xe} + \lambda_J} \leqslant M^2\mu_s^2, \tag{8a}$$

where $\lambda_s = \Phi_s \sigma_{aXe}$ (σ_{aXe} – xenon absorption cross section); λ_{Xe} – xenon decay constant; λ_j iodine decay constant; and $A\chi_s$ - the changes in the coefficient of multiplication due to xenon poisoning weighted by the space harmonic.

The authors wish to express their deep gratitude to B. M. Udgaonkar for his support and valuable advice and also to A. S. Anikindi for his help in performing the calculations.

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ISOTHERMIC IRRADIATION OF NONFISSIONABLE MATERIALS IN THE RFT REACTOR BY MEANS OF CALORIMETRIC DEVICES

N. F. Pravdyuk, V. N. Kuznetsov, and N. I. Leletin

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pp. 380-386, November, 1960
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The present article is concerned with the generation of heat due to the absorption of the energy of γ-radiation from the reactor spectrum in nonfissionable materials when they are irradiated in the reactor core. The calculated dependence of the γ-radiation energy mass absorption coefficient on the atomic number for the RFT spectrum was plotted [1]. A steady-state method for determining the amount of heat q generated per unit mass of nonfissionable materials when they are irradiated in heat-producing assemblages, which has been developed in using RFT, is described here. The obtained values for aluminum, Steel 30, tin, and lead vary from 2.2 to 3.7 w/g for cylindrical specimens with diameters equal to 13.5 and 10 mm and a 10-Mw reactor power level. The dependence of q on the distance to the reactor central line within the core zone has a cosinusoidal character. A method which is used for isothermic irradiation of specimens and containers at temperatures above the coolant temperature is described.

Heat Generation in Nonfissionable Materials

For materials which are inefficient fast neutron moderators and which weakly absorb thermal neutrons, γ-radiation is the main heat producing source in irradiation inside a reactor. The heat release per unit mass of the specimen material due to the absorption of γ-radiation with the energy E can be expressed by the equation

$$q_\gamma = (J_\gamma)_E \left(\frac{\mu_{en}}{\varrho}\right)_E f_E(\bar{l},\ Z), \tag{1}$$

where J_γ is the γ-radiation energy flux density, μ_{en} is the linear energy absorption coefficient, ρ is the material density, and $f(\bar{l}, Z)$ is a factor which takes into account the attenuation of the γ-radiation flux inside the specimen and which depends on the specimen dimensions and material ($\bar{l} = (4V/S)$ is the specimen effective dimension; Z is the atomic number).

For γ-rays with the energy E, μ_{en} is usually given by

$$\mu_{en} = \mu_0 - \sigma_s = \tau + \sigma_a + \varkappa, \tag{2}$$

where μ_0 is the linear attenuation coefficient for narrow beams, σ_s is the linear Compton scattering coefficient, τ the linear photoeffect coefficient, σ_a is the linear Compton absorption coefficient, and $\varkappa$ is the linear coefficient of pair generation.

In the case where the γ-radiation field varies only slightly near the specimen at distances of the order of $1/\mu_{en}$, the $f(\bar{l}, Z)$ factor is related by a simple expression to the self shielding coefficient of a source whose shape and the material are the same as those of the specimen and to the uniform radiation generation throughout the volume [2], i.e.,

$$f(l, Z) = 1 - P. \tag{3}$$

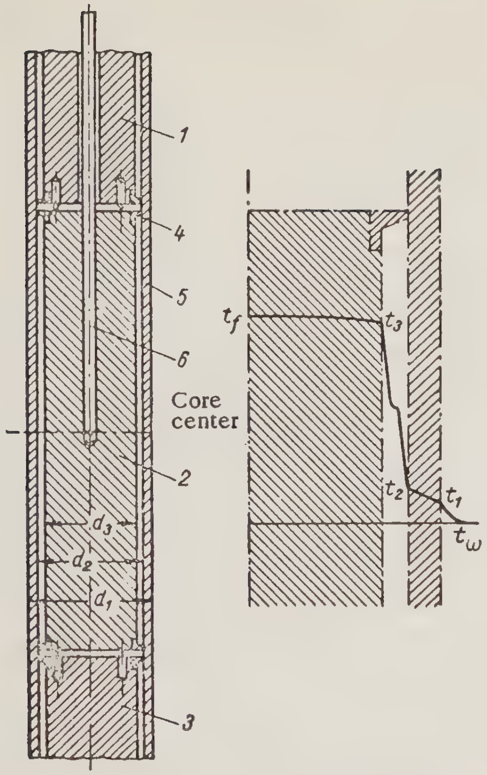

Fig. 1. Diagram of the calorimeter and the temperature distribution (t_f is the temperature at the slug center; t_1, t_2, and t_3 were not measured; t_ω is the water coolant temperature.

Heat Release in Long Cylindrical Specimens Inside Heat-Producing Assemblages which Were Placed in the Core Center of the RFT Reactor for a Reactor Power Level of 10 Mw

Material	Specimen Diameter mm	Heat released, w/g		
		q	q_n	q_γ
Aluminum	13,5	2,3±0,4	0,22	2,08
Steel 30	13,5	2,2±0,4	0,35	1,85
Tin.	10	3,1±0,5	0,012	3,088
Lead. . . .	10	3,7±0,6	0,014	3,686

The values of the self-shielding coefficient for sources with different shapes are given, for instance, in [3]. The expression for heat generation in the specimen due to the absorption of γ-radiation energy for the spectrum can be written thus:

$$q_\gamma = \int_0^\infty J_\gamma(E)\,\frac{\mu_{en}(E)}{\varrho}\,f[\mu_{en}(E),\ \bar{l}]\,dE. \tag{4}$$

If the average linear coefficient of the γ-spectrum energy absorption is defined as

$$\bar{\mu}_{en} = \frac{\int_0^\infty \mu_{en}(E)\,J_\gamma(E)\,dE}{\int_0^\infty J_\gamma(E)\,dE}, \tag{5}$$

then, by taking into account the rather weak dependence of the $f[\bar{\mu}_{en}(E),\ \bar{l}]$ function on E, expression (4) can be written as

$$q_\gamma = J_\gamma \frac{\bar{\mu}_{en}}{\varrho} f(\bar{\mu}_{en},\ \bar{l}). \tag{6}$$

Since the interactions of neutrons with the specimen atoms make a contribution to the heat generation (elastic and inelastic scattering of fast neutrons, absorption of the capture radiation occurring in the specimen, absorption of the radiation resulting from the decay of the specimen radioactive atoms, etc.), the over-all amount of heat released per unit mass of the substance can be represented by the sum $q = q_\gamma + q_n$. Then, if the heat release in any specimen of an elementary substance with the dimension l_0 which is characterized by the μ_{en0} value is known, the heat release in a specimen made of any material of complex composition and of any size can be calculated by using the equation

$$y_k = (q_0 - q_{n_0})\left(\frac{\bar{\mu}_{en}}{\varrho}\right)_k \left(\frac{\bar{\mu}_{en}}{\varrho}\right)_0^{-1} \times \frac{f(\bar{\mu}_{en_k},\ \bar{l}_k)}{f(\bar{\mu}_{en_0},\ \bar{l}_0)} + q_{n_k}, \tag{7}$$

while, due to the absorption additivity

$$\left(\frac{\bar{\mu}_{en}}{\varrho}\right)_k = \sum_{i=1}^{k} \eta_i \frac{\bar{\mu}_{en_i}}{\varrho_i},$$

where index k pertains to the entire specimen consisting of k constituents; index 0 pertains to a specimen consisting of the known elementary substance, and i pertains to the compound constituent; η_i is the relative weight of each constituent.

The values of q_n are usually much smaller than the corresponding values of q_γ [4], and, therefore, it is sufficient to determine q_n only approximately. This can be done in a simple manner if, instead of the irradiation of specimens, the thermal and the fast neutron flux values are known. In this, it can be considered that all

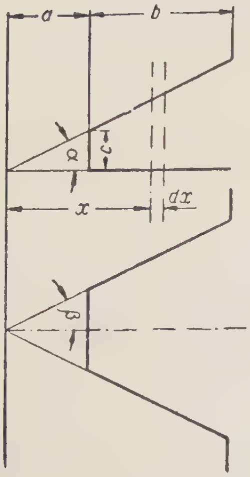

Fig. 2. Centering rib.

the internal emitters for the above specimen activity are in equilibrium, that, in the case of γ-radiation, the radiation energy is absorbed only partially in dependence on μ_{en} and the specimen dimensions, and that the radiation energy is absorbed completely in the case of corpuscular radiation. In determining the energy released in the specimen due to the elastic scattering of fast neutrons, it can be considered that the entire energy of fast neutrons that is generated in a certain reactor cell is absorbed by the cell elements in correspondence with their dimensions and moderating power.

Experimental Investigation of Heat Release

For some metals and alloys, q was determined in the central zone of the RFT fuel element assemblages by using the steady-state calorimetric method. The calorimeter (Fig. 1) consisted of a tube, 5, with a diameter of 16/1 or 25/1.5 mm, which was hermetically sealed by welding at the lower end and left open at the top. The tube outside surface was cooled by the coolant. Its lower part contained a chain of three to five cylindrical slugs, 1, 2, and 3, each having a length of 100 mm, which were facing the core center. The insulation between the slugs and the tube consisted of a cylindrical air clearance and of eight centering ribs, 4, which were made in the shape of truncated cones and were provided at the ends of each slug. The tube itself, as well as the measuring thermocouples 6, were extended to the outside of the core. The middle slug, 2, was used as the working slug, which made it possible to neglect the end effects. The t_f temperature was measured by means of a copper-constantan thermocouple and a potentiometer with an accuracy to ± 1°C, and the value of t_ω was determined by means of resistance thermometers by measuring the water coolant temperature at the channel input and output.

In order to be able to determine the heat removed from the slug with respect to the difference between the t_f and t_ω temperatures, we shall determine the heat losses due to heat conduction through the centering ribs. Considering that the actual rib shape is the same as that given in Fig. 2, we shall assume that ideal contact exists between the rib and the tube. If we neglect the removal of heat from the rib lateral surfaces, we shall obtain the heat flux through the transverse cross section at x, which is independent of x. Then, with the coordinate origin at the apex of the triangle, by denoting the cross-sectional area at x by $\Omega(x)$, and considering that the heat flux direction is opposite to the positive direction of the axis of abscissas, we shall write, according to Fourier's law, the following equation:

$$Q = \lambda \Omega(x) \frac{dt}{dx} = 2\lambda \operatorname{tg} \alpha \operatorname{tg} \beta x^2 \frac{dt}{dx},$$

i.e.,

$$Q = 2(t_3 - t_2) \lambda \operatorname{tg} \alpha \operatorname{tg} \beta \frac{a(a+b)}{b},$$

where λ is the thermal conductivity coefficient of the rib material.

According to the necessities dictated by the design, the following values were used: b = 0.2 mm, c = 0.1 mm, and $\alpha = \beta = 45°$. The amount of heat removed through all of the ribs constituted to 2–5% of the total heat release in the slug; thus, it could be neglected. Then, under steady-state conditions, the heat generated in the slug can be equated to the heat removed through the air clearance:

$$Q\text{gen} = qm = \pi k_l (t_f - t_\omega) l, \tag{8}$$

where m is the working slug mass, and k_l is the linear heat transfer coefficient.

If, for the sake of simplicity, we assume that heat is not generated in the material of tube 5 (see Fig. 1), the total thermal resistance will be given by

$$\frac{1}{k_l} = \frac{1}{4\lambda_s} + \frac{1}{2\lambda_{a.eff}} \ln \frac{d_2^*}{d_3^*} + \frac{1}{2\lambda_T} \ln \frac{d_1}{d_2} + \frac{1}{\alpha_1 d_1}, \tag{9}$$

where λ_s and λ_t are the heat transfer coefficients of the slug and the tube materials, α_1 is the coefficient of heat transfer to the water, d_2^* and d_3^* are the air clearance diameters at the working temperatures, and $\lambda_{a.eff}$ is the effective thermal conductivity coefficient of the air in the clearance, which, if convection is neglected, is given by

$$\lambda_{a.\mathrm{eff}} = \lambda_a + \left[\varepsilon_n C_0 \frac{\left(\frac{T_3}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4}{T_3 - T_2} \right] \frac{d_3}{2} \ln \frac{d_2}{d_3}.$$

Here, λ_a is the air thermal conductivity coefficient, ε_n is the reduced radiation coefficient, and C_0 is the black-body radiation coefficient.

The table provides the experimental values of $\underline{q}$ in watts per gram for some of the materials which were placed in the reactor core for an over-all reactor power level of 10 Mw. The estimated measurement accuracy was ± 16 %. The values of q_n were calculated, and the values of q_γ were given as the difference q-q_n. In calculating q_n, the thermal neutron flux was assumed to be equal to 10^{14} neutrons/cm^2 sec, the flux of fast neutrons with an energy greater than 1 Mev was assumed to be 3.5×10^{13} neutrons/cm^2 sec, and the power of a single heat-producing assemblage was assumed to be 500 kw. The value of $\underline{q}$ for aluminum that is given in the table represents the average value obtained from several measurements in different core channels, and the values of $\underline{q}$ for the other materials were obtained as a result of single measurements and were converted afterwards, so that all results pertain to the same slug position for a certain average point in the core with respect to heat release. It should be noted that the values of $\underline{q}$ can differ to a considerable extent for different channels (up to ± 50%); however, no explicit dependence of $\underline{q}$ on the channel heat output was observed.

In order to determine to what an extent the obtained results agree with expression (7), we calculated the dependence of $\bar{\mu}_{en}/\rho$ on the atomic number Z for the RFT γ-spectrum by using expression (5). Figure 3 shows the corresponding diagram, where, according to expression (2), also the components are given. Since the RFT γ-spectrum was not measured directly, the spectrum obtained on the basis of measurements performed on the IRT reactor was accepted [5]. The use of these data for RFT was sufficiently justified, since enriched uranium is used as the fuel in both reactors. Certain differences can be expected in the capture radiation spectra. In correcting the spectrum, it was assumed that the IRT capture radiation spectrum was mainly formed by water and aluminum, and that the RFT capture radiation spectrum was formed by water, aluminum, and stainless steel, since neutron absorption in graphite could be neglected. It was further assumed that the absorption capacity of aluminum was approximately equal in both cases. In the first approximation, it can be considered that the absorbing capacity of water in RFT is equal to absorption capacity of stainless steel. Therefore, the intensity of the H(n, γ) D line E = 2.23 Mev in the IRT spectrum was reduced by one-half, while, at the expense of this line, the high-energy portion of the spectrum in the 6.5-9 Mev energy interval, which is due to neutron absorption in iron, nickel, and chromium in RFT, was enlarged. The above approximation appears to be sufficient. Moreover, the IRT spectrum was corrected by taking into account the absorption in 10 cm of graphite with the density $\rho \approx 1.8$ g/cm^3.

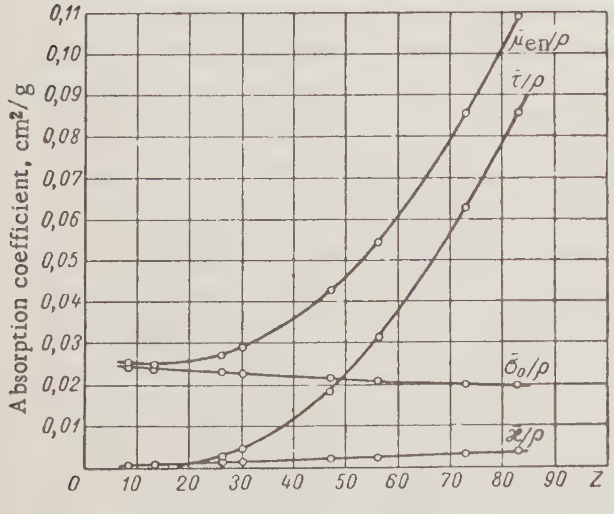

Fig. 3. Dependence of the mass absorption coefficient for the reactor spectrum γ-radiation energy on the atomic number.

The thus obtained dependence of the number of γ-quanta per energy unit interval on the energy in the 2-6 Mev interval approximately corresponds to an exponential with the 1.01 E exponent. The value of $\bar{\mu}_{en}/\rho$ was calculated for eight different elements, while the spectrum was approximated by means of 12 groups .

Figure 4 shows the values of $\frac{\mu_{en}}{\varrho} f(\bar{\mu}_{en}, d)$ for cylindrical specimens in dependence on the atomic number Z for different values of the $\bar{\mu}_{en}$, d product. The values of $f(\bar{\mu}_{en}, d)$ were determined by using expression (3). The same figure shows the calculated as well as the experimental (tabular) values q_γ of the heat released in specimens of the materials under consideration in arbitrary units, which are arranged according to the principle of "least squares." For steel, it was assumed that Z = 26. By correcting the value of q_γ according to Fig. 4 and by using expression (6), we can find I_γ, for instance, for aluminum, i.e., we can find the average density of the γ-radiation energy flux

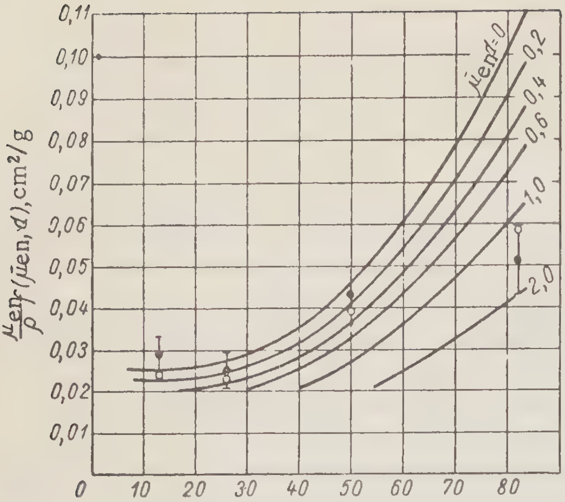

Fig. 4. Dependence of the $\frac{\bar{\mu}_{en}}{\varrho} f\,(\bar{\mu}_{en},\ d)$ product for the γ-radiation spectrum on the atomic number Z for different values of $\bar{\mu}_{en}d$. ○) Calculated values of q_γ for aluminum, Steel 30, tin, and lead in arbitrary units; ●) experimental values of q_γ.

inside the heat-producing assemblages within the limits of the q measurement accuracy. In this, it appears that $\bar{I}_\gamma = (4.5 \pm 0.7) \times 10^{14}$ Mev/cm² sec, which, if the spectrum shape is taken into account, corresponds to a dose rate equal to $P = (7.5 \pm 1.2)10^8$ r/hr.

By remote manipulation by means of an electric motor, the slugs were moved along the calorimeter tube, where by the distribution of q along one of the channels was obtained for 5-, 7-, and 10-Mw reactor power levels. The corresponding curves are given in Fig. 5, where the value of q at the core center for a power level of 10 Mw is taken as unity. The distribution within the core zone is close to the cosinusoidal distribution. If we denote by u the distance from the core center to the slug center along the vertical, the heat released in the slug will be

$$q = q^1_{cc} \quad N \cos\frac{\pi u}{1380},$$

where q^1_{cc} corresponds to the position at the core center for a reactor power level of 1 Mw, and N is the power in megawatts.

Isothermic Irradiation

It is known that, under steady-state conditions, the temperature distribution along the radius of an infinite cylinder with uniformly distributed internal heat sources is parabolic. The maximum temperature drop from the center toward the generatrix is in our case equal to

$$t_f - t_3 = q\varrho\frac{d_3^2}{16\lambda_s}.$$

For an aluminum-jacketed slug and a q of the order of 2-3 w/g, this value will not exceed 2°C. By taking this into account, the obtained results can be readily extended to the case of prolonged isothermic irradiation of specimens made of nonfissionable materials at certain assigned temperatures. For this, the problem opposite to that considered above must be solved, i.e., the heat exchange conditions must be determined for the known heat release in the slug with respect to the assigned t_f and t_ω values. Having determined q_0 according to the calorimetric method, we can find the heat release in the slug by using expression (7) and Fig. 4. The necessary heat exchange conditions can be secured in practice by choosing a suitable magnitude of the ring-shaped clearance, which constitutes the main thermal resistance component. In this, the lower attainable temperature limit is t_ω (more accurately, t_2), and the upper limit is determined by the value of q and the material density in the slug for a given calorimeter diameter. The specimens must fit well in the corresponding slug openings in order to secure the minimum difference between the slug and the specimen temperatures.

The error in determining the value of q, which arises in calculating the thermal resistance by using expression (9), has no great significance. If the value of q would have to be determined for the purposes of other experiments, for instance, radiation dosimetry experiments, the calorimeter would have to be calibrated by introducing a certain given heat energy into the slug by electrical means, and the actual thermal resistance would have to be determined. The use of the obtained values of q for the purpose of only solving the reverse problem automatically eliminates the basic portion of this error, and the accuracy of securing the assigned temperatures in this case mainly depends on the stability of radiation fluxes in the channel. In our experiments, this stability was in most cases such that the assigned temperatures were maintained with accuracy of ±30°C over a period of many days. For instance, in irradiating a large batch of specimens of structural materials for metallographic investigations at different temperatures in the 100-400°C region and for an average irradiation duration of somewhat less than one month in several tens of calorimetric devices, the average arithmetical deviation from the assigned temperature was from +24° to −33°C.

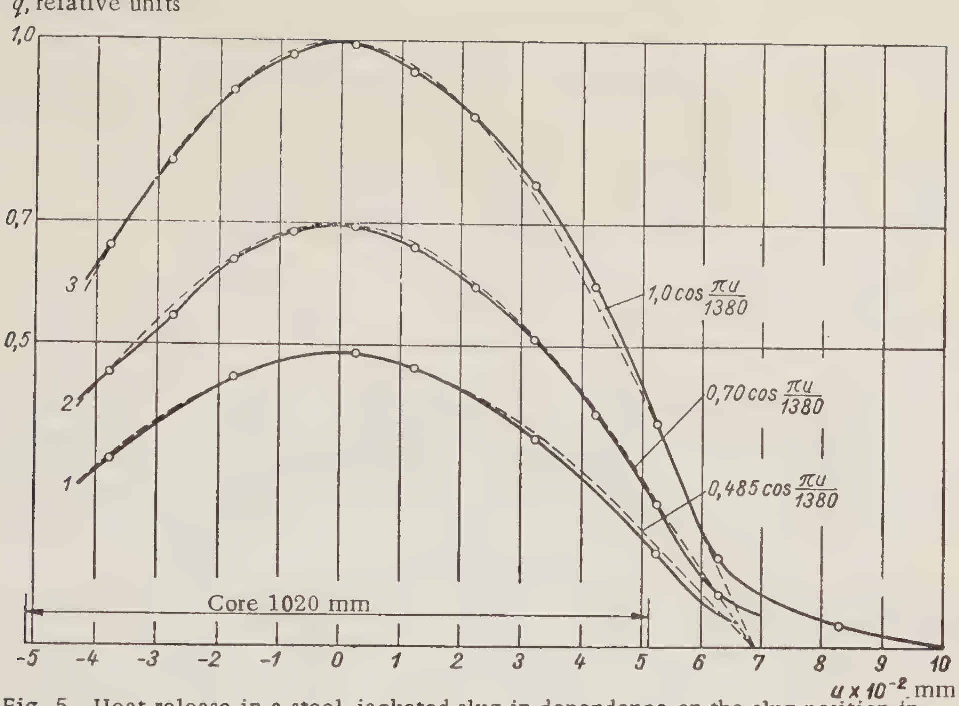

Fig. 5. Heat release in a steel-jacketed slug in dependence on the slug position in an RFT channel for three different power level values (negative u values correspond to the case where the slug was located below the reactor central line). 1) 5 Mw; 2) 7 Mw; 3) 10 Mw.

The gradual variation of the q value along the channels makes it possible to provide fine temperature adjustment in the slugs during the reactor operation by moving the slugs by means of remote control devices. Naturally, in this, the slug must be provided with an indicator which would fix the neutron flux integral value.

The described method can also be used for irradiating structures with small specimens of fissionable materials. Since the over-all amount of heat released in the slug will be greater in this case than in irradiating only nonfissionable materials, the air clearance magnitude can be reduced for the same working temperature. Consequently, the amount of fissionable material in the specimen will be limited by a rational magnitude of the air clearance.

CONCLUSIONS

1. The heat release per unit mass in any multiconstituent material caused by the absorption of the reactor γ-radiation energy can be determined if the γ-spectrum and the heat release in a specimen of any elementary substance are known.

2. Isothermic irradiation of specimens of nonfissionable materials in a reactor at temperatures above the coolant temperature and attaining 400-600°C can be secured with an accuracy of ~ ± 30°C by means of special slugs with air clearance insulation if a sufficiently intensive γ-field is present in the reactor lattice.

3. This method can also be used for irradiating small specimens with fissionable materials.

4. The assigned temperatures can be maintained with a greater accuracy if the slugs with the specimens are moved along the channels by means of remote control devices, i.e., if the smooth space variation of the radiation intensity is utilized.

In conclusion, the authors extend their thanks to V. A. Sidorenko for his contribution to the discussion of the results.

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URANIUM MONOCARBIDE

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Uranium monocarbide is of interest as a possible nuclear fuel and material for nuclear thermoelectrical transformations. In order to accurately define the effect of the conditions for preparing uranium monocarbide (UC) on its composition, studies were made which established the optimum regime for preparing UC with a stoichiometric composition.

Studies were made of the conditions for sintering and hot pressing of UC powder and also conditions for sintering UC + U alloys, giving specimens with a porosity of about 5%. The specific gravity of UC powder determined by a pycnometer is 12.97 ± 0.09 g/cm^3, microhardness of the phase – 923 ± 56 kg/mm^2.

The thermal conductivity of UC in the range 100-700°C varies from 0.028 to 0.04 cal/cm·sec·deg; the mean thermal coefficient of linear expansion in the range 20–1500° is $11.6 \cdot 10^{-6}$. Specimens of UC subjected to cyclic heat-treatment in the range 200–1000° withstood 500 cycles without failure. Specimens of UC + U withstood more than 1000 cycles.

Uranium monocarbide can be obtained by various methods and is used as a material for the cores of fuel elements in nuclear reactors [1, 2] and also for the direct conversion of atomic energy to electrical energy in thermoelectric converters [3].

The advantages of UC as a nuclear fuel are its high melting point (2275°C), thermal conductivity (0.05 cal/cm × sec·deg at 100°C [4]) and the fairly high volume concentration of uranium (12.95 g in 1 cm^3). Another important fact is that UC does not undergo phase transformations and is isotropic, since it has a cubic crystalline lattice. The carbon in UC has a small thermal neutron capture transverse cross section. The regeneration of fuel elements with UC is fairly simple. However, due to the hardness, brittleness and refractoriness the preparation of components of UC is difficult. The hot pressing of uranium monocarbide powder in graphite in die-casting molds used for forming from refractory materials is not very productive. Furthermore, with this method it is difficult to produce components whose length is much greater than their transverse dimensions or components of complex shape. Components obtained by sintering after preliminary cold pressing of the powder are usually very porous, which spoils their physical and mechanical properties.

To intensify the sintering process and increase the density of the sintered bodies from refractory carbides it is usual to sinter the carbides with the addition of more fusible cementing metals [5]. For uranium monocarbides this addition is metallic uranium. The UC + U alloy is classed as a cermet and is of interest for use in fuel elements [1].

Preparing UC powder. The initial mixture of powders of uranium dioxide and carbon black was prepared in accordance with the equation

$$UO_2 + 3C = UC + 2CO$$

taking into account the actual oxygen content in the UO_2. The pressed briquets of the UO_2 + C mixture were roasted under varying conditions in a beryllium oxide crucible in a vacuum furnace with a graphite heater. The carbide briquette obtained was broken down into powder with particles less than 10-15 μ. An atmosphere of argon dried with phosphorous pentoxide was used for all operations with the UC powder and for its storage. In order to determine the temperature of the start of reaction [1], a manometric analysis was carried out (Fig. 1). It was found that with an initial pressure of 10^{-4}mm Hg and a rate of heating of 50°C /min the reaction begins with a noticeable velocity at 1300°C (shown by the increase in pressure in the furnace). The following are the calculated equilibrium pressures of carbon monoxide in reaction [1]:

Temperature, °C	1000	1100	1200	1300	1400	1500
Pressure, p_{CO}, mm Hg.	$1 \cdot 10^{-3}$	0,18	1,5	8	43	180

A comparison of the experimental data with the calculated data shows that in practice the reaction is noticeable at temperatures which are 200–250°C higher than the calculated equilibrium temperature.

Table 1 gives results for a study of the dependence of the chemical composition of monocarbide on the temperature at which it was produced (experiments 1 and 2), the content of carbon black in the initial charge (experiments 3-6), time of soaking (experiments 2, 6, 8) and on the residual pressure in the furnace (experiments 9, 10). It follows from these experiments that the best system for producing UC is: heating to 1800°C and soaking after reaching the initial pressure for 10-30 min. The obtained monocarbide contains not more than 0.1% of free carbon; the content of combined carbon agrees with the calculated value (4.8%) within the limits of accuracy of the analysis.

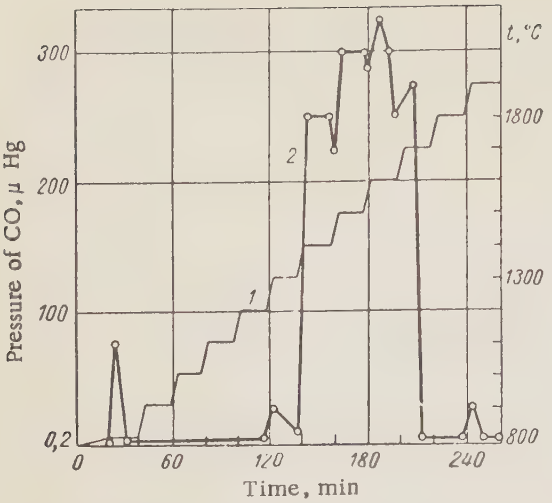

Fig. 1. Manometric curve with stepwise increase in temperature: 1) curve for stepwise increase in temperature; 2) curve for increase in pressure (liberation of CO).

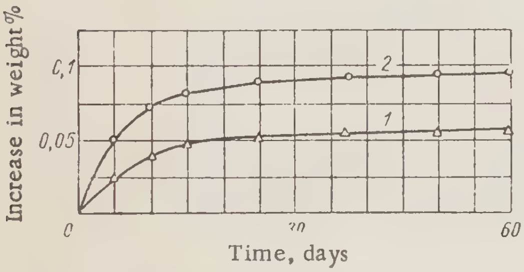

Fig. 2. Change in weight of UC in air with time: 1) UC powder of grain size 10-20 μ with paraffin; 2) the same powder of UC without paraffin.

TABLE 1.

The Effect of Reduction Conditions on the Chemical Composition of UC

No. of experiment	Amount of C in charge, % of stoichiometric	Reduction conditions			Chemical analysis of product, weight %				
		maximum temperature, °C	soaking at maximum temperature and residual pressure, min	residual pressure, μ	U	C_{tot}	C_{free}	C_{comb} by difference	total $U+C_{tot}$
1	100	1600	0	0,2	93,50	5,11	1,07	4,04	98,61
2	100	1800	0	0,2	94,77	4,90	0,18	4,72	99,67
3	86	1800	10	0,2	95,13	3,55	0,03	3,55	98,68
4	95	1800	10	0,2	94,90	4,44	0,03	4,41	99,34
5	100	1800	10	0,2	94,76	5,00	0,07	4,93	99,76
6	105	1800	20	0,2	93,71	5,69	0,05	5,68	99,40
7	100	1800	60	0,2	94,71	5,00	0,11	4,89	99,71
8	100	1800	60	0,2	94,75	4,89	0,06	4,83	99,82
9	100	1800	60	50	94,91	4,91	0,13	4,78	99,82
10	100	1800	60	350	94,79	4,91	0,17	4,74	99,70

TABLE 2.

Coefficient of Linear Expansion ($\times 10^6$)

Material	Temperature range, °C		
	20–600	20–1000	20–1500
UC	8.9	10.0*	11.6*
UC + 20 wt. % U	12.4	–	–

*Extrapolated

TABLE 3.

Change in Properties of Specimens of UC + 20 Wt. % U Due to Cyclic Heat-Treatment (200 – 1000°C, 1000 cycles)

Properties	Before heat treatment	After heat treatment	Change, %
Length, mm	13.32	13.48	+ 1.2
Density, g/cm^3	13.44	13.38	– 0.5
Specific electrical resistance, μ·ohm·cm	66.0	66.6	+ 1.0

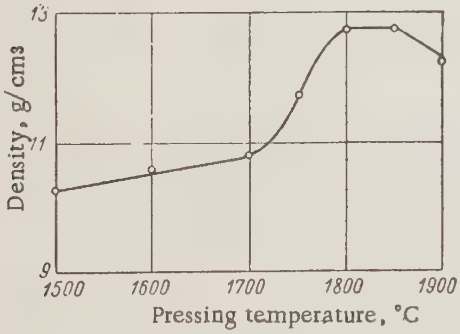

Fig. 3. Relationship between the density of hot pressed specimens and the pressing temperature (p = 300 kg/cm^2; τ = 5 min).

An x-ray study showed that the product had a single phase and that the crystalline lattice parameter (a_0 = 4.9512 ± 0.0003 kX) agreed with the previously published value (4.951 ± 0.004 kX [6]). The specific gravity of the UC powder measured in kerosene with micropycnometer [7] with an x-ray density of 13.63 g/cm^3 was 12.97 ± 0.09 g/cm^3.

Measurements were also made of the rate of oxidation of different specimens of UC powder with change in weight on being kept in air. Figure 2 shows curves for the change in weight of UC powder (grain size 10-20 μ) and UC powder whose particles were covered with paraffin (2 weight %). The paraffin reduces the rate of oxidation of UC to a small extent. After the addition of paraffin the finest UC powders were no longer pyrophoric.

Preparing Dense Specimens of UC by Hot Pressing. A graphite die-casting mold was placed in a hermetically sealed metal vacuum chamber in which the residual pressure was ~ 10 mm Hg. A study was made of the effect of the pressing pressure, temperature and time of soaking on the density of the specimens. Linings of molybdenum foil were used to prevent the UC carburizing to UC_2 by contact with the graphite die-casting mold.

Figure 3 shows a curve for the relationship between density of specimens and temperature of hot pressing. The reduction in density with increase in temperature above 1850°C is due to the fact that at a temperature greater than the figure mentioned the molybdenum lining reacts with graphite, is carburized, cracks and loses its protective properties.

Hot pressing gave dense pieces of UC with porosity about 5% (with height to diameter ratio of 1:1).

Figure 4 shows the microstructure of a compact specimen of UC obtained by hot pressing.

Preparing Compact Specimens of UC and UC + U by Separate Pressing and Sintering. Briquets pressed from UC powder and also from a mixture of UC + U with varying contents of uranium (9.5–31.8 wt. %) were charged into a graphite crucible, the bottom of which was covered with zirconium carbide or tantalum carbide and were sintered in a vacuum furnace with a graphite heater.

Figure 5 shows the dependence of the porosity and electrical resistance of sintered specimens of UC and UC + U on the sintering temperature. After sintering UC at 2200°C for 2 hr the residual porosity is 10%.

The addition of metallic uranium sharply increases the density and with a uranium content of 25 volume % (31.8 wt. %) by sintering at 1700°C for 2 hr it is possible to obtain specimens with a porosity of 5% or less.

As shown by the microstructure of sintered specimens of UC + U (Fig. 6) during sintering there is a considerable increase in size of the UC grains and there is a change in their shape, which points to the recrystallization of UC through the molten uranium. This is the reason for the intense increase in density of specimens of this composition during sintering.

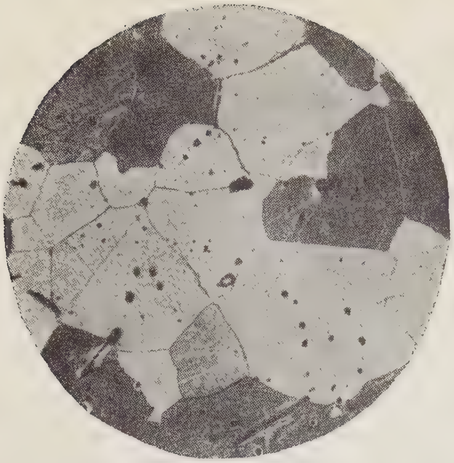

Fig. 4. Microstructure of hot pressed UC ; the section was etched with a mixture of $HNO_3 + CH_3COOH + H_2O$ (× 200).

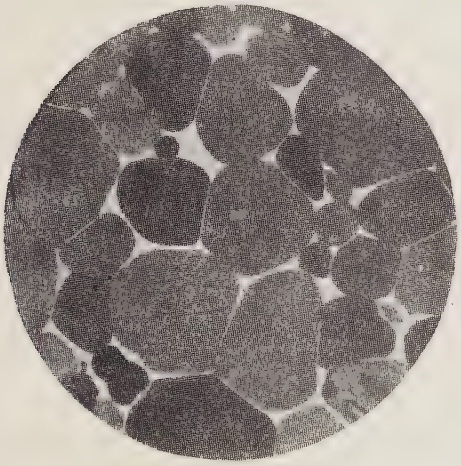

Fig. 6. Microstructure of UC + 20 weight % U; the section was etched with a mixture of $HNO_3 + CH_3 \cdot COOH + H_2O$ (× 200).

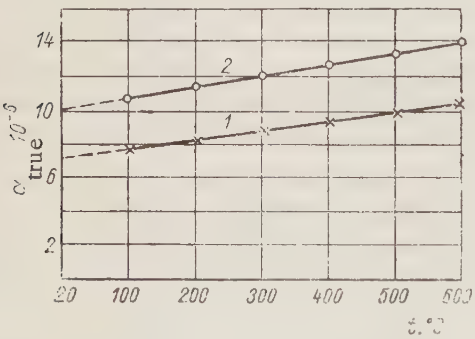

Fig. 8. Dependence of the true thermal coefficient of linear expansion α on the temperature. 1) UC; 2) UC + 20 weight % U.

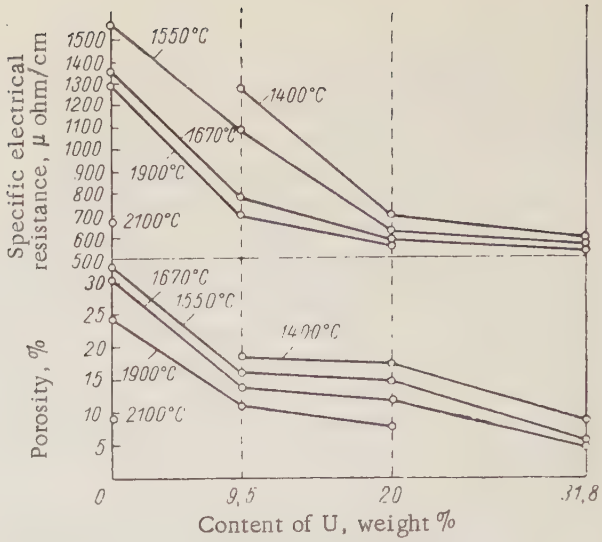

Fig. 5. The dependence of the porosity and the specific electric resistance of sintered specimens of UC + U on the amount of uranium added and the sintering temperature (soaking for 2 hr).

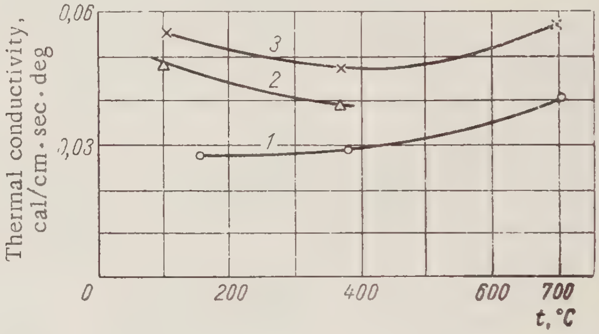

Fig. 7. The thermal conductivity of UC and UC + U as a function of the temperature: 1) UC; 2) UC calculated from the law of additions from the data of thermal conductivity of an alloy UC + 20 weight % U; 3) UC + 20 weight % U.

The microhardness was measured on a PMT-3 instrument with a 50g load on etched sections and for the UC phase it was 923 ± 56 kg/mm² and for the uranium layers it was 376 ± 24 kg/mm². The fact that the layers have a greater microhardness than the pure uranium is probably due to the hardening effect which is observed in thin metallic layers enclosed between grains of hard phase.

Properties of UC and Alloys of UC + 20 Weight % U. The thermal conductivity was determined on sintered specimens in the range 100-700°C. The results (after converting to zero porosity according to the formula $\lambda_0 = \lambda_{por} \frac{1}{1-\Pi}$) are given in Fig. 7.

The thermal coefficient of linear expansion was measured on a Chauvenar differential optical dilatometer.

Figure 8 shows the change in the true coefficient of linear expansion with temperature. Table 2 gives the calculated values for the mean coefficient of linear expansion in various temperature ranges.

Behavior of UC and UC+ 20 Weight % U during Cyclic Heat-Treatment. Specimens of UC and UC + 20 weight % U of diameter 6 mm and length 13 mm, sealed in a quartz ampoule filled with helium, were heated by a high frequency current. The time of heating was 30 sec and the material was cooled (to ~200°C) for about 20 sec without soaking at the minimum and maximum temperatures.

Specimens of pure UC of porosity ~ 15% mostly withstood 500 cycles of cyclic heat-treatment in the range 200–1000°C.

As a rule, specimens of the alloy UC + 20 weight % U withstood more than 1000 cycles without failure. The external appearance of the specimen was unaltered after the tests.

The linear dimensions, density and electrical resistance of the specimens before and after 1000 cycles in the range 200–1000°C are given in Table 3, from which it can be seen that the changes in these properties are very small. No changes were found in the microstructure.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

INCREASE IN INTERNAL FRICTION IN URANIUM WITH CHANGE IN TEMPERATURE

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Original article submitted April 4, 1960.

On the basis of the previously described increase in internal friction in uranium during heating, a semiquantitative evaluation was made of the dependence of increase in internal friction on the rate of heating, frequency and amplitude of vibrations. The results of the calculations agree satisfactorily with data obtained experimentally. A study was made of the effect of the initial state of the specimen on the increase in internal friction at the initial stages of heating.

INTRODUCTION

It was shown in [1] that with change in temperature of uranium specimens there is a sharp increase in the internal friction, which is not observed in cubic isotropic metals—aluminum and molybdenum. The increase in internal friction is due to microstresses and strains which occur in the grains of polycrystalline specimens due to anisotropic change in shape of the grains with change in temperature.

It was found that internal friction of uranium specimens during heating at constant rates increases with time, reaching a certain limiting value. The increase in internal friction increases approximately proportional to the rate of heating of the specimen and falls almost to the original value immediately after the temperature becomes constant.

A study was made of the effect on the increase in internal friction of parameters such as the temperature range in which the heating was carried out, grain size, texture of specimen, etc. Macroscopic shear deformation of the specimens was also observed—"departure from zero" of the vibrations. An arrangement was considered which explained the processes occurring in the grains of uranium with change in temperature of the specimen, this arrangement being basically similar to that advanced in [2] to explain the increase in internal friction in a lead tube with increase in pressure in it.

THEORY

On the basis of the process described in [1] a semiquantitative evaluation will be made of the dependence of increase in internal friction on the rate of heating, frequency and amplitude of vibrations. An accurate calculation of the stresses introduced in the grains is impossible since the grains are differently orientated, have an incorrect shape, are surrounded by a large number of differently orientated crystallites, etc. The stress state changes considerably from grain to grain. The discussions given below are therefore schematic; however, they can be used to draw correct conclusions as to the dependence of internal friction on a number of parameters.

We will consider the deformation and stress in one of the grains in the internal part of the specimen (Fig. 1). During heating the α-uranium grain changes its shape anisotropically. For the sake of simplicity we will assume that the action of the surrounding grains on a given grain is equivalent to the action of an inelastic thermally isotropic matrix with a mean linear coefficient of expansion. In this case at a constant rate of heating the deformation will be equal in absolute value and opposite in sign to the change in the relative size of the grain caused by thermal expansion.

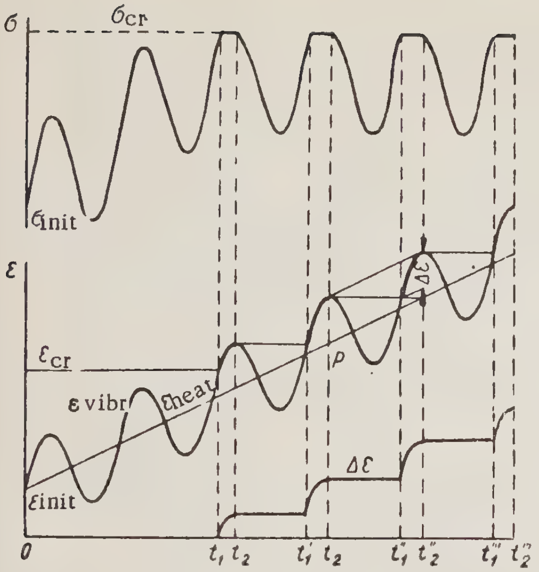

Fig. 1. Arrangement of deformation ε and stresses σ in a grain of α-uranium caused by anisotropic expansion of crystallites during heating and vibrational movements of the pendulum. The curve Δε shows the value of the active plastic deformation due to torsional vibrations of the pendulum.

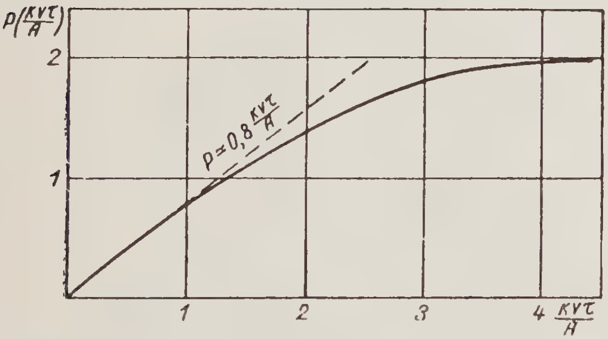

Fig. 2. Dependence of the function $p=\frac{\Delta\varepsilon}{A}$ on $\frac{kv\tau}{A}$.

At a constant rate of heating v

$$\frac{d\varepsilon_{heat}}{dt} \simeq a\Delta\alpha v, \tag{1}$$

where a is the coefficient of proportionality, whose value depends on the grain size, their mutual orientation and positions; $\Delta\alpha$ is the change in relative grain sizes with change in temperature by 1°C.

As is known [3], in the temperature range 20 −300°C the axial coefficients of thermal expansion of α-uranium are: $\alpha_a = 28.8 \times 10^{-6}$; $\alpha_b = -0.4 \cdot 10^{-6}$; $\alpha_c = 23.5 \cdot 10^{-6}$.

The mean linear coefficient of thermal expansion of α-uranium $\alpha_m = 17.3 \cdot 10^{-6}$. Assuming in the first approximation that the deformation of an α-uranium grain due to reaction with the surrounding matrix amounts to its elongation along the b axis with simultaneous compression along the a and c axes, we obtain $\Delta\alpha = \alpha_m - \alpha_b = 18 \cdot 10^{-6}$. Therefore, on heating with v = 10 °C/min and a = 1.

$$\frac{d\varepsilon_{heat}}{dt} = 0{,}30 \cdot 10^{-5}\ \text{sec}^{-1}.$$

According to the data of [1] the macroscopic shear deformation of the specimens was $1.7 - 5 \cdot 10^{-8}$ sec^{-1}, i.e., 0.6 − 1.7% of the value of total deformation of a separate grain (at a = 1). If it is remembered that on the average the deformations of separate grains compensate one another, then this type of relationship can be perfectly reasonable.

At the first stages of heating the deformation will be elastic, therefore, the stresses increase in proportion to the deformation. When the total stresses (caused by the thermal expansion of the grain and the torsional vibrations of the pendulum) reach a value σ_{cr} (see Fig. 1) at an instant t_1, plastic deformation commences, which will proceed up to the instant t_2 – the start of decrease in stresses. In the following cycle the plastic deformation commences at the instant t'_1, when the stresses again increase to σ_{cr}, etc. The increase in internal friction during change in temperature of the specimen is connected with the expenditure of elastic energies of vibrations on the plastic deformation Δε.

The work of deformation of the grain

$$\Delta U = b\sigma_{cr}\Delta\varepsilon V, \tag{2}$$

where V is the grain volume; b is the coefficient of proportionality, depending on the same parameters as the coefficient a.

The corresponding increase in internal friction

$$\Delta = \frac{1}{2}\frac{\Delta U}{U} fN = \frac{b\sigma_{cr}\Delta\varepsilon}{GA^2} f, \tag{3}$$

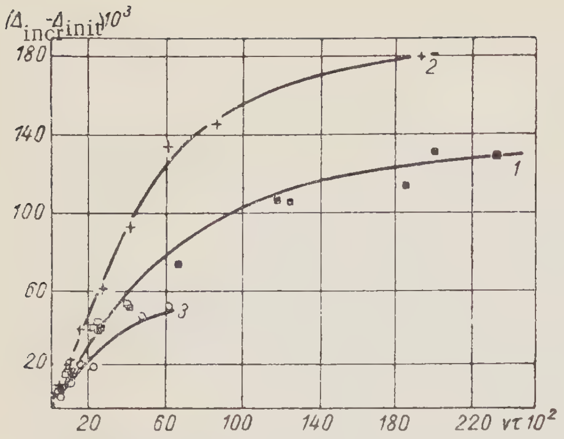

Fig. 3. Dependence of the increase in internal friction in uranium specimens during heating in the temperature range 20–120°C on the product $v\tau$: 1) hardened specimens of composition B (□ – τ = 0.5 sec; ◘– τ = 2.6 sec); 2) hardened specimens of composition A(τ changed, $\underline{v} \simeq 11$ °C /min); 3) annealed specimens of composition B (τ changed, $\underline{v} \simeq 11$ °C /min). The continuous lines show the corresponding calculated data.

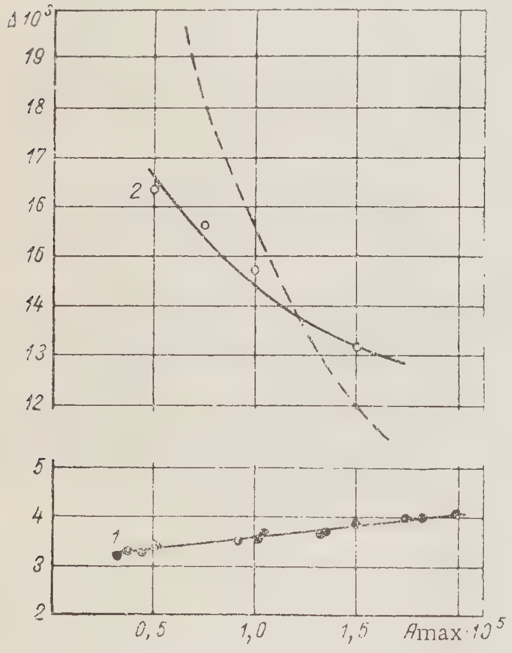

Fig. 4. The amplitude dependence of internal friction in uranium hardened from the γ-region (specimen of composition A): 1) at room temperature; 2) when heated in the temperature range 20-120°C ($v \simeq 8$ °C /min, τ = 0.4 sec). The broken line shows the dependence calculated by formula (6).

where $f = \frac{n}{N}$ – is the relative number of grains in which plastic deformation occurs; $U = \frac{GA^2}{2}VN$ is the elastic energy of vibrations; N is the number of grains in the specimens; A is the amplitude of the deformation caused by torsional vibrations; G is the shear modulus ($G \simeq 8 \cdot 10^3$ kg/mm^2).

According to Fig. 1, the value of the active deformation accompanying the expenditure of energy of elastic vibrations $\Delta\varepsilon$ is equal to the toal value of plastic deformation during the cycle minus the plastic deformation due to thermal expansion of the grain during time Δt:

$$\Delta\varepsilon = \frac{d\varepsilon_{heat}}{dt}(\tau - \Delta t) = a\Delta\alpha v\tau\left(1 - \frac{\Delta t}{\tau}\right), \tag{4}$$

where τ is the period of vibrations; $(1 - \frac{\Delta t}{\tau})$ is determined from the condition that the deformation at the instant t''_1 is equal to the deformation at the instant t'_2.

Taking the point $\underline{p}$ (Fig. 1) as the origin, we obtain

$$A = a\Delta\alpha v(\tau - \Delta t) + A\cos\frac{2\pi}{\tau}(\tau - \Delta t);$$
$$\cos 2\pi\left(1 - \frac{\Delta t}{\tau}\right) = 1 - \frac{kv\tau}{A}\left(1 - \frac{\Delta t}{\tau}\right), \tag{5}$$

where

$$\frac{a\Delta\alpha v\tau}{A} = \frac{kv\tau}{A}.$$

The graphic solution of equation (5) can determine $(1 - \frac{\Delta t}{\tau})$ as a function of $\frac{kv\tau}{A}$ in the range up to $\frac{kv\tau}{A} = 4$. The results of the calculation in the form of the function $P\left(\frac{kv\tau}{A}\right) = \frac{\Delta\varepsilon}{A} = \frac{kv\tau}{A}\left(1 - \frac{\Delta t}{\tau}\right)$ are shown in Fig. 2.

At $\frac{kv\tau}{A} \geq 4$ the active plastic deformation will continue for $\frac{d\varepsilon_{vibr}}{dt} > 0$, i.e., a half of the period; in the second half of the period the deformation caused by the pendulum will slow down the rate of deformation caused by the change in temperature of the specimen and there will be no losses of elastic energy of vibrations. Consequently, for $\frac{kv\tau}{A} > 4$ $P = 2$.

To compare the calculated data with the experimental values it is essential to consider the change in amplitude across the section of the specimen:

$$A = \frac{r}{R}A\max$$

where A_{max} is the amplitude of vibrations at the surface of the specimen for r = R(R is the radius of the specimen). Substitution of this expression in formula (3) and its integration across the section of the specimen give the following

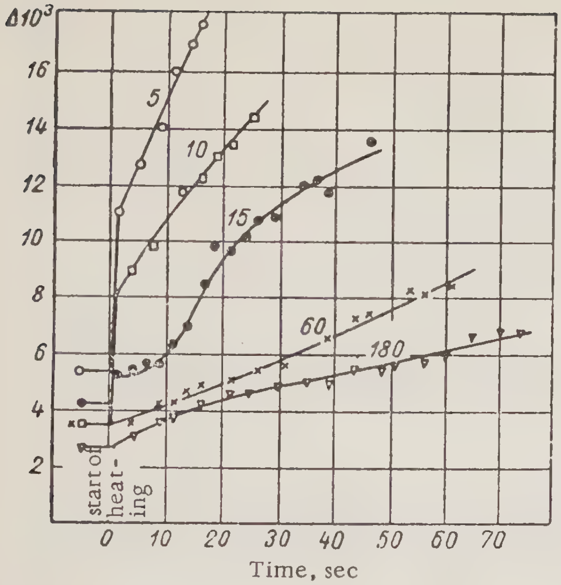

Fig. 5. The effect of soaking after preliminary heating on the increase in internal friction at the initial stage of heating from 70 to 120°C ($v \simeq 9$ °C /min, $\tau = 0.5$ sec). The numbers on the curves indicate the duration of soaking at 70°C (min).

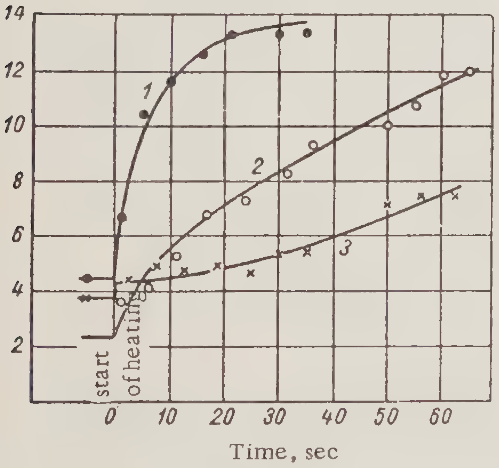

Fig. 6. The effect of preliminary heating and cooling on the increase in internal friction at the initial stages of heating from 120 to 170°C ($v \simeq 9$ °C /min); 1) after heating with $v = 0.4$ °C/min for 45 min; 2) after 4 hr soaking at 120°C; 3) after cooling with $v = 0.3$ °C /min for 60 min.

expression for internal friction:

$$\Delta = \frac{2b\sigma \mathrm{cr}}{GA\mathrm{max}}\,\frac{2}{R^3}\times \int_0^R f\left(\frac{r}{R}A\mathrm{max}\right)P\left(\frac{kv\tau}{A}\,\frac{R}{r}\right)r^2\,dr, \qquad (6)$$

where $f(\frac{r}{R}A_{\max})$ is a function characterizing the dependence of the relative number of grains taking part in the deformation on the amplitude. The internal friction can be calculated by taking as a first approximation $f = mA$ ($\underline{m}$ is the coefficient of proportionality). In this approximation for $\frac{kv\tau}{A} < 1$

$$\Delta = \frac{2b\sigma_{\mathrm{cr}}}{G}\,\frac{1{,}6}{3}\,m\,\frac{kvt}{A_{\max}} \text{ and for } \frac{kvt}{A} > 4$$

$$\Delta = \frac{2b\sigma \mathrm{cr}}{G}\,m.$$

For intermediate values of the argument $\frac{kv\tau}{A}$ the internal friction can be calculated by graphic integration.

It can be seen from the formulas given that the increase in internal friction depends on the product $v\tau$ (i.e., on the increase in temperature during one period of vibration) and is proportional to the argument at small values of $\frac{kv\tau}{A}$. For large values of $\frac{kv\tau}{A}$ the increase in internal friction is constant.

The results of calculations for a number of investigated specimens in Fig. 3 are compared with the experimental data.

METHOD OF EXPERIMENT

All the measurements were made on the apparatus previously described in [1]. The method of measurements was basically the same but there were a few differences. For example, the investigations at low frequencies (< 1 cps) were carried out in air, since the length of the inert pendulum was greater than the dimensions of the vacuum bell jar. This led to a very small increase in internal friction which, however, was much smaller than the increase in internal friction caused by the heating.

To reduce the frequency of vibrations, in a number of cases specimens of diameter 0.7 mm were used and not 1 mm, which somewhat increased the stresses introduced in the specimen by the weight of inert pendulum; however, this increase in stresses had no effect on the internal friction. In the study of the amplitude dependence of the internal friction and also in the study of change in internal friction a photographic record was made at the first stage of heating. The uranium investigated had the following chemical composition (main impurities, weight %):

Designation of specimen material	C	Fe	Si	Al
A	0,037	$2,1 \cdot 10^{-3}$	$4,5 \cdot 10^{-3}$	-
B	0,049	$8,3 \cdot 10^{-3}$	$1,4 \cdot 10^{-2}$	$1,4 \cdot 10^{-2}$

Wire specimens of diameter 1 and 0.7 mm were prepared by wire drawing according to the previously described [1] technique. The specimens were studied in the hardened state after soaking in the γ-phase at 850°C for 2 hr and quenching in water (the mean grain size in the specimens of composition A was 15-25 μ, for composition B it was 50 μ) and in the annealed state after annealing in the γ-phase at 850°C for 2 hr and tempering at 600°C for 4 hr (the grain size in the composition B specimens was 0.2-0.4 mm).

RESULTS OF EXPERIMENT

Dependence of the Increase in Internal Friction on the Rate of Heating and the Period of Vibrations. Measurements showed that the curves for the dependence of increase in internal friction on the time of heating at various values of τ and $v \leq 50$ °C/min are similar to those which were observed previously at $\tau = 0.5$ sec and $v \leq 20$ °C/min.

The increase in internal friction as a function of the product $v\tau$ during heating in the range of temperatures 20–120°C is shown in Fig. 3. The data obtained at low and high frequencies lie almost on the same curve 1, which confirms the correctness of the above assumptions on the dependence of internal friction on the product $v\tau$. The experimental data then agree satisfactorily with the calculated data represented in Fig. 3 in the form of a continuous line. In the calculations it was assumed that $A_{max} = 1 \cdot 10^{-5}$ and in the specimen there was an equal number of grains with $k_1 = 1.4 \cdot 10^{-5}$ and $k_2 = 2.8 \cdot 10^{-5}$.

The measurements of the dependence of increase in internal friction on the frequency on heating in the range of temperatures 20-120°C with $v = 11$ °C/min were carried out on hardened specimens of composition A (the measurements at a frequency < 0.3 cps were carried out on specimens of diameter 0.7 mm). The results of these measurements and also similar measurements made on coarse-grained annealed metal of composition B are also given in Fig. 3. In these cases the character of the change in increase in internal friction is similar to that of the change in increase in internal friction shown by curve 1. The experimental data agree satisfactorily with the calculated curves obtained with the same assumptions as for curve 1, but with somewhat different values of the constants (for curve 2, $k_1 = 1.7 \cdot 10^{-5}$; $k_2 = 3.4 \cdot 10^{-5}$, and for curve 3, $k_1 = 2.5 \cdot 10^{-5}$ and $k_2 = 5 \cdot 10^{-5}$).

The data given also explain the absence of an increase in internal friction on heating at a frequency of ~1000 cps [3]. The increase in internal friction decreases with increase in frequency of vibrations and at a frequency of 1000 cps it is very small.

The increases in internal friction are different for the three investigated types of specimens. In experiments at a frequency of 2 cps it was shown that the increase in internal friction in the annealed metal of composition B is about a half of that in the hardened metal of composition A. As can be seen from Fig. 3, this difference is maintained over the whole investigated range of the product $v\tau$.

According to a calculation with formula (6) (assuming that $b = 1$ and $\sigma_{cr} = 0.2$ kg/mm^2) the relative number of grains f taking part in the deformation at $A = 1 \cdot 10^{-5}$ for a hardened metal of composition A is 4.3 %, for a hardened metal of composition B it is 2.3% and for an annealed metal of composition B it is 1.2%. The smaller value in the coarse-grained specimen is explained by the fact that in it most of the grains emerge onto the surface and the expansion of the grains occurs more freely: the smaller value in the hardened metal of composition B compared with metal of composition A can also be explained by the somewhat coarser grain or residual texture.

The relative number of grains taking part in the deformation is small. This is because most of the grains have an orientation which is unfavorable for deformation and do not take part in the deformation caused by vibrations of the pendulum. Since in the determination of the stress state of the grain the geometry of the mutual position of the grains in the specimen is not taken into account, the above calculations should be considered approximate.

The Amplitude Dependence of the Increase in Internal Friction in Uranium During Heating. The investigation of the amplitude dependence of internal friction involves considerable experimental difficulties due to the small interval of time during which the heating takes place, the continuous change in internal friction at the first stages of heating, etc. Despite these difficulties, the amplitude dependence of internal friction of uranium during heating was established (Fig. 4). At room temperature the internal friction of uranium depends little on the amplitudes of the vibrations, increasing by about 0.35×10^{-3} with increase of A_{max} from 0.25 to 1.0×10^{-5}. During the heating the internal friction decreases with increase in amplitude. This coincides qualitatively with the results of the theoretical calculation (see the broken lines on Fig. 4), according to which at $(kv\tau/A) < 1$ (which was the case in experiments on the determination of the amplitude dependence of internal friction)

$$\Delta \sim \frac{1}{A_{max}}$$

(on the assumption that $f = mA_{max}$).

However, the experimental dependence of the increase in internal friction on the amplitude is best characterized by the expression

$$\Delta = 7.2 \cdot 10^{-3} + 3.5 \cdot 10^{-3} \frac{1}{A_{max}} \quad .$$

The agreement of the experimentally found dependence with the dependence calculated theroretically can be obtained by assuming that f increases with the amplitude:

$$f = m_1 A + m_2 A^2 \ .$$

The Effect of the Initial State of the Specimen on the Increase in Internal Friction. The character of the change in internal friction at the initial stages of heating is affected by the initial state of the specimen. Curves have been obtained for the dependence of the internal friction of a specimen of hardened uranium of composition B on the time during heating with $v \simeq 9°C/min$. The heating was carried out in two stages: preliminary heating from 20 to 70°C, followed by soaking at this temperature and the main heating from 70 to 120°C. The results are shown in Fig. 5. The internal friction in the main stage of heating immediately after the start of heating sharply increases almost to the limiting value; the value of the initial jump in internal friction and the slope of the internal friction vs. time curve are large. The value of the increase in internal friction at the first stage of heating is considerably affected by those internal stresses ($\sigma_{init.}$), which were formed in uranium due to the preliminary heating.

With increase in the time of soaking at 70°C the initial jump in the value of the internal friction and the slope of the internal friction vs. time curve decreased; this indicates the relaxation of internal stresses. If we assume that the stress relaxation proceeds proportional to $e^{-\beta t}$, then the value of β calculated from the experimental data will be equal to $\sim 10^{-3}\ sec^{-1}$.

Preliminary cooling causes elastic stresses of the opposite sign (with respect to the stresses introduced during heating) in the grains. To remove these stresses during heating additional time is needed, therefore, the increase in internal friction in this case should be slowed down. Figure 6 shows the change in internal friction in the case where the heating in the range 120-170°C was carried out directly after slow cooling from 150 to 120°C. For comparison purposes curves are also given for the change in internal friction after prolonged soaking at 120°C and after slow preliminary heating in the range 90-102°C. The effect of the stressed state caused by preliminary treatment is obvious.

SUMMARY

It was shown that the change in temperature of a polycrystalline uranium specimen intensified the relaxation processes in it, resulting in an increase in internal friction. The value of the increase in internal friction depends mainly on the product $v\tau$, i.e., the increase in temperature during one period of vibration. At small values of $kv\tau/A$ the increase in internal friction is proportional to the product $v\tau$, at large values the proportionality is disturbed and the increase in internal friction reaches saturation. The results of a semiquantitative evaluation of this process agree satisfactorily with the experimental results.

The internal friction at the initial stages of heating is strongly affected by the internal stresses remaining in the uranium after preliminary heat-treatment. The elastic stresses arising in uranium due to preliminary heating or cooling are relaxed during soaking at room temperature.

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CROSS SECTIONS FOR THE FISSION OF Th^{232}, U^{235}, AND U^{238} INDUCED BY 10-22 Mev NEUTRONS

V. M. Pankratov, N. A. Vlasov,
and B. V. Rybakov

Translated from Atomnaya Énergiya, Vol. 9, No. 5,
pp. 399-401, November, 1960
Original article submitted July 21, 1960

There is still very little data on the behavior of the fission cross section for neutrons of energies above 10 Mev [1]. This is due to measurement difficulties connected, firstly, with the lack of suitable neutron sources, and, secondly, with the presence of large backgrounds from the accompanying neutrons. Neutrons from the widely used D(d, n) He^3 and T(d, n)He^4 reactions cease to be monoenergetic for deuteron energies exceeding the break-up threshold. Other reactions in which heavier residual nuclei are produced give complex line-spectra.

In the present work, we used the reaction D(d, n)He^3 for the neutron source. To remove the above mentioned difficulties, we carried out a time-of-flight analysis, owing to which we were able to separate the effect associated

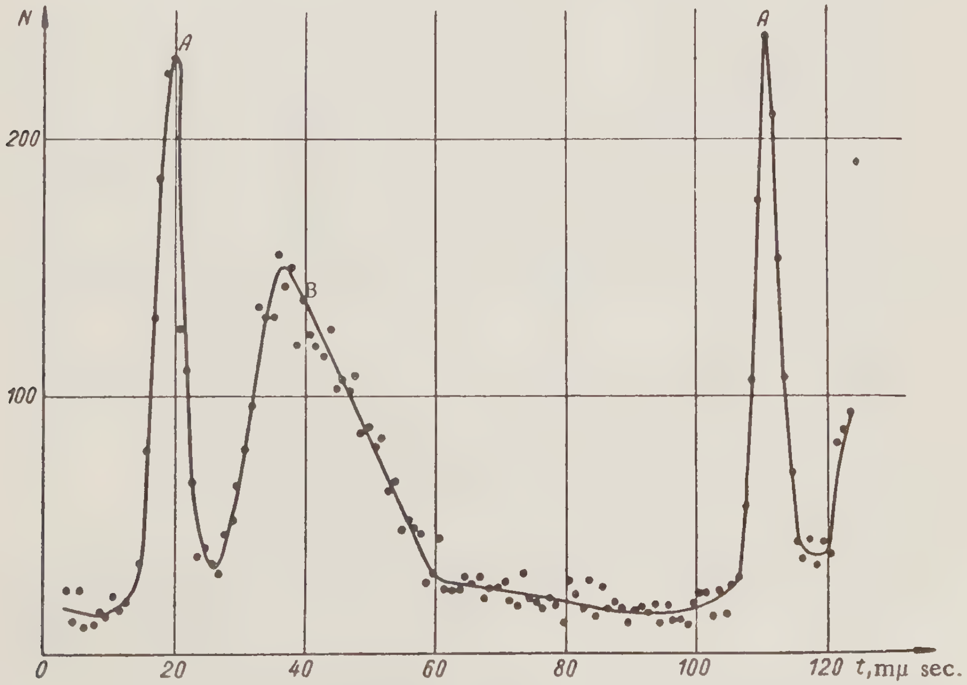

Fig. 1. Time spectrum of Th^{232} fission pulses. A) Neutrons from the D(d, n)He^3 reaction; B) neutrons from the D(d,pn)D reaction.

with the monoenergetic neutrons of this reaction. The deuteron energy was varied from 6.5 to 19.5 Mev corresponding to a neutron energy of from 9.7 to 21.7 Mev) by means of replaceable platinum foils placed in front of the target. The neutron energy spread determined by the thickness of the target of deuteron gas was 250 kev at E_d = 19.5 Mev and 700 kev at E_d = 6.5 Mev. All measurements were made at an angle of 0° with respect to the deuteron beam.

To record the acts of fission, we used a gas scintillation fission chamber filled with xenon and an FÉU-33 photomultiplier. The photomultiplier pulses were applied to the imput of a time-of-flight multi-channel spectrometer [2]. Figure 1 shows the time distribution of the observed acts of Th^{232} fission for E_d = 19.5 Mev and flight distance of 3 m. The narrow peak represents the effect of 21.7 Mev monoenergetic neutrons from the D(d, n)He^3 reaction. The broad peak corresponds to fission induced by neutrons produced in the break-up of the deuterons, and the pedestal of the peak is an effect from the scattering and slowing down of the neutrons. Similar distributions were also obtained for other isotopes at energies of E_d = 6.5-19.5 Mev. The area of the peak corresponds to the total number of acts of fission induced by monoenergetic neutrons in the layer. If the absolute intensity of these neutrons and the number of nuclei in the layer are known, then we can calculate the fission cross section.

The intensity of the neutron flux from the D(d, n)He^3 reaction for different values of E_d was measured on a scintillation counter with an 8 cm diameter and 3 cm high tolane crystal connected to the time-of-flight spectro-

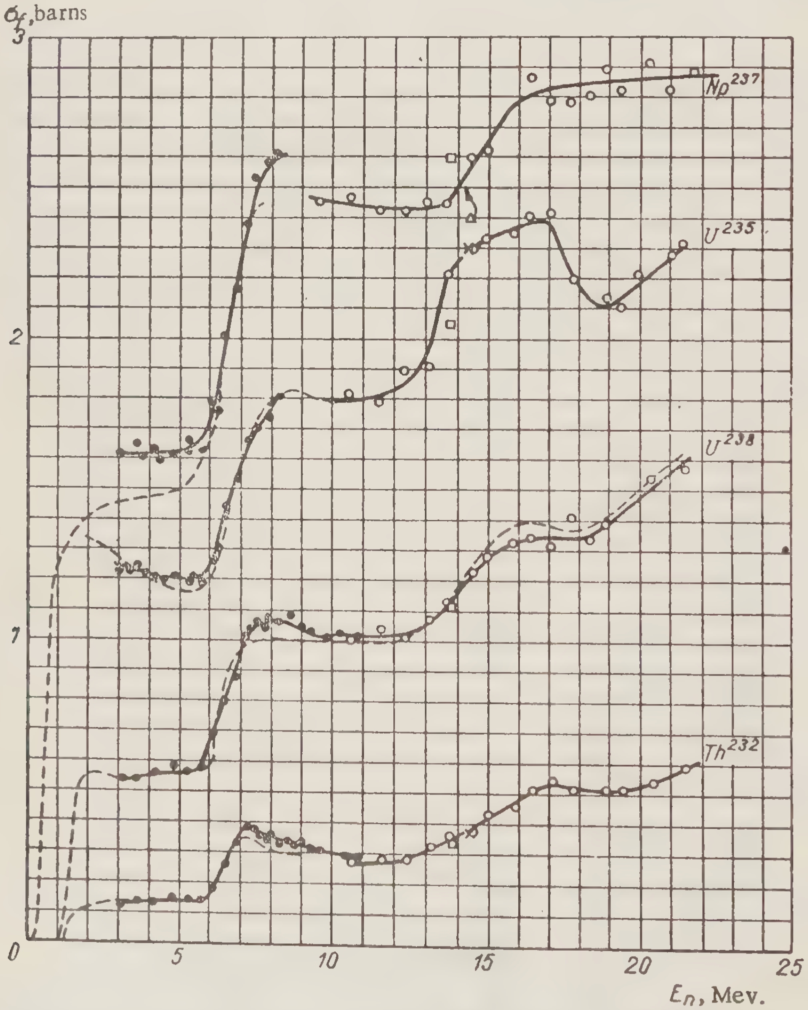

Fig. 2. Cross section for fission of Th^{232}, U^{238}, Np^{237}, and U^{235} induced by neutrons of energy 3-22 Mev. ●—neutrons from the T(p, n)He^3 reaction [5]; ○—neutrons from the D(d, n)He^3 reaction; □—data of [1]; x—data of Berezin et al. [4]; △—data of Protopopov et al. [4].

meter circuit. The scale of the amplitude selector, set at the counter threshold, was calibrated in energy units and the counter efficiency was calculated by the method of [3]. The measurements were made for values of the threshold approximately equal to half the neutron energy.

The amount of substance in the chambers was not determined. We therefore determined only the relative fission cross sections as a function of the energy; the absolute value of the cross section was found by the relation between the obtained curves and the results of the measurements at $E_n = 14$ Mev [1, 4] quite accurately for all the enumerated isotopes, except Np^{237}, for which a difference of approximately 10% was obtained.

Figure 2 shows the results obtained. The statistical error of the measurement is nowhere poorer than 3%. The error in the relative shape of the cross section curves did not exceed ± 5% and was also determined on the basis of the accuracy of the flux measurements of neutrons from the $D(d, n)He^3$ reaction. The initial segments of the curves for $E_n < 12$ Mev were constructed on the basis of previous measurements [5].* The dotted curves indicated the results of the measurements made at the Los Alamos laboratory [1]. The fission cross sections over the entire energy range were measured at the Los Alamos laboratory only for U^{238}. Our results for U^{238} are in satisfactory agreement with these data.

In general, the fission cross sections for all isotopes increase with energy, in qualitative agreement with what is expected. However, quantitative agreement is not observed in all cases. In particular, the fission cross section of thorium, which apparently also does not attain values close to the cross section for the inelastic interaction at greater energies increases appreciably less than one should expect on the basis of the semiempirical dependence on Z^2/A.

In the shape of the U^{235} fission cross section curve, one observes a rather sharp nonmonotonicity, apparently connected with the fact that the (n, 3n) reaction threshold is approximately 1.5 Mev higher than the tertiary fission threshold. There is a certain "jump" in the cross section of Th^{232} at $E_n = 7$-9 Mev for this reason. A jump in the value of the U^{235} cross section is observed not at the second stage, as for Th^{232}, but at the third stage at $E_n = 15$-17 Mev. The U^{235} fission cross section in the energy range of 15-22 Mev is also somewhat lower than expected.

The authors thank S. P. Kalinin for consultations and aid in solving problems connected with the method, N. I. Venikov, A. A. Kurashov, and the group they direct for ensuring the proper functioning of the equipment.

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*A small correction was introduced for the results of [5].

CROSS SECTIONS FOR THE RADIATIVE CAPTURE OF FAST NEUTRONS BY THE ISOTOPES V^{51}, Nb^{93}, W^{186}, AND Tl^{205}

Yu. Ya. Stavisskii and V. A. Tolstikov

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Original article submitted April 27, 1960

The neutron cross sections were measured by the relative activation method [1, 2] in the energy interval of $E_n = 0.03 - 2.1$ Mev. The reaction $T(p, n)He^3$, produced with the aid of a Van de Graaf generator, was used for the neutron source.

An angle of 95° was used for activation by neutrons of energy $E_n < 300$ kev and an angle of 0° for activation by neutrons of energy $E_n > 300$ kev. The neutron energies for the measurements at angles of 95 and 0° overlapped somewhat. The agreement in the cross sections for the overlapping energy regions is evidence of the reliability of the measurements. The energy spread of the neutrons was determined by the thickness of the tritium target, the geometrical dimensions of the samples, and the instability of the accelerating potential of the accelerator. The energy spread was ± 12-20 kev for neutron energies up to 200 kev and ± 30-40 kev for higher neutron energies. The thermal neutron activation was carried out in the thermal column of a fast reactor.

In the analysis of the results of the measurements, the thermal neutron activation cross sections were taken from the atlas [3]. The fast neutron capture cross sections for the I^{127} isotope standard were taken from [4] and supplemented by the results of our measurements of the I^{127} capture cross section relative to the U^{235} fission cross section [3]. The statistical accuracy of the results was ± 2-5%. The error in the energy curve of the cross sections was determined on the basis of the errors in the U^{235} fission cross sections ($\sim 25\%$ for $E_n < 60$ kev, $\sim 12\%$ for $E_n = 60-150$ kev, $\sim 8\%$ for $E_n > 150$ kev). The results of the measurements of the cross sections for radiative capture of fast neutrons by the isotopes V^{51}, Nb^{93}, W^{186}, and Tl^{205} are shown in Figs. 1-4.

For neutrons of energy $E_n > 150$ kev, the results of our measurements of the V^{51} and W^{186} cross sections are in agreement with the data of Barschall [3]. The Tl^{205} capture cross section decreases in the neutron energy interval up to $E_n \simeq 50$ kev; at $E_n \simeq 50-120$ kev, it remains constant within the limits of error, but some structure in the cross section curve is observed, which, perhaps, can be explained by resonances in the Tl^{205} total cross section [3]. For $E_n > 120$ kev, the cross section decreases monotonically. The value of the Tl^{205} capture cross section obtained in the present work is in agreement, within the limits of error, with the value obtained by us previously for an Sb-Be photoneutron source [1]. The results of [11] lie about 20% below the cross sections of our experiment.

For niobium, we measured essentially the cross section for the production of the Nb^{94*} isomer by radiative capture of neutrons. If the corresponding isomer ratio for transition from thermal to fast neutron capture does not change, then the measured cross section coincides with the capture cross section. The results obtained are in good agreement with the neutron data for the fission spectrum of [8]. The results of our experiments with an Sb—Be photoneutron source [1] lie considerably below the data of the present work. It is difficult to indicate the reason for the discrepancy.

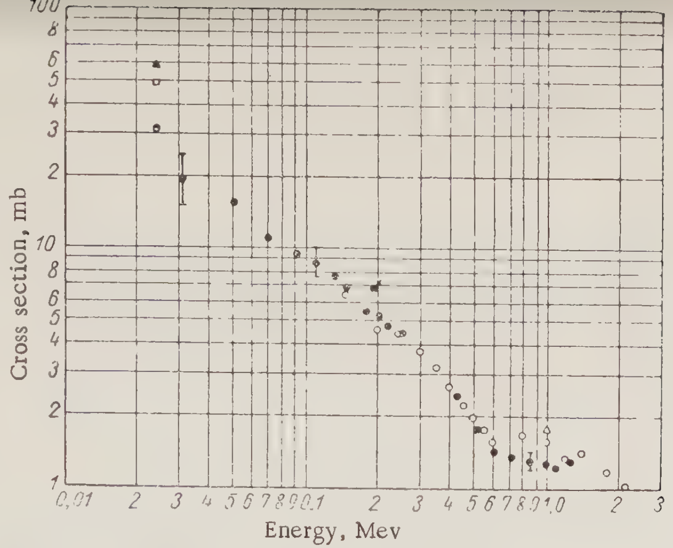

Fig. 1. Variation of the cross section for the radiative capture of fast neutrons by the V^{51} isotope with the neutron energy. Data from: ●-present work; ◒-[1]; □-[5]; ○-Barschall's measurements [3]; ▲-[6]; × [7]; △- [8]; ■-[9].

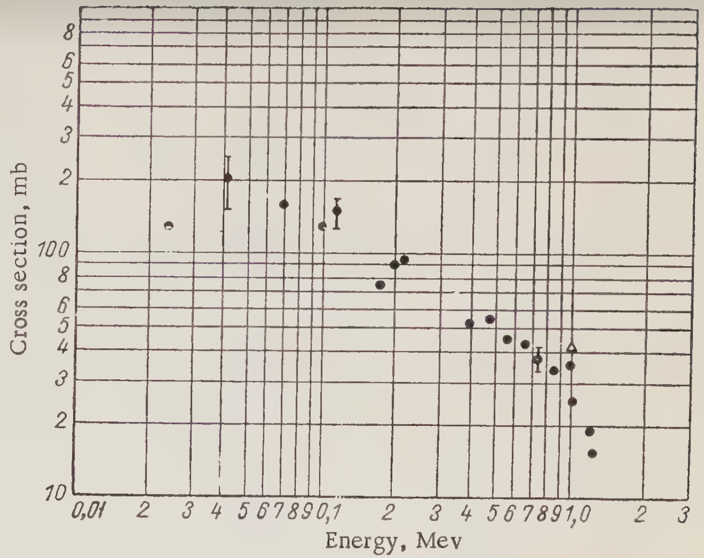

Fig. 2. Variation of the cross section for the radiative capture of fast neutrons by the Nb^{93} isotope with neutron energy. Data from: ● - the present work; ◒ - [1]; △- [8].

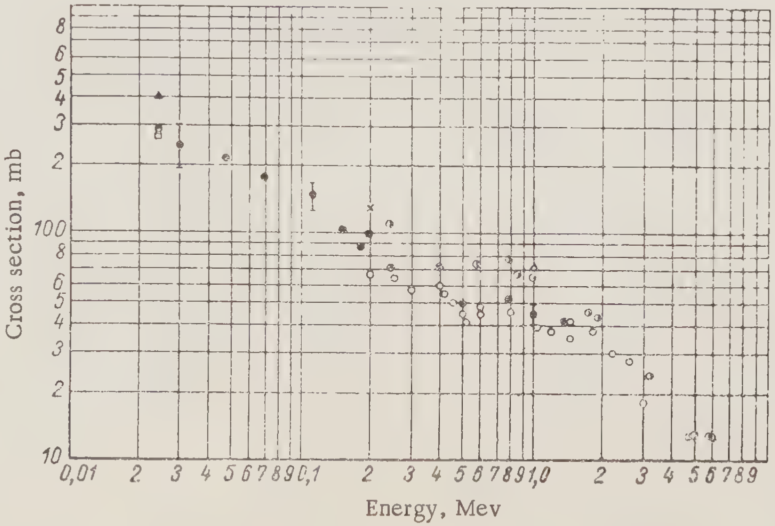

Fig. 3. Variation of the cross section for the radiative capture of fast neutrons by the W^{186} isotope with neutron energy. Data from: ●-the present work; ◒-[1]; ◑-University of California; ○-Barschall's meaurements [3]; △-[8]; ×-[7]; □-[10]; ■-[9]; ▲-[6].

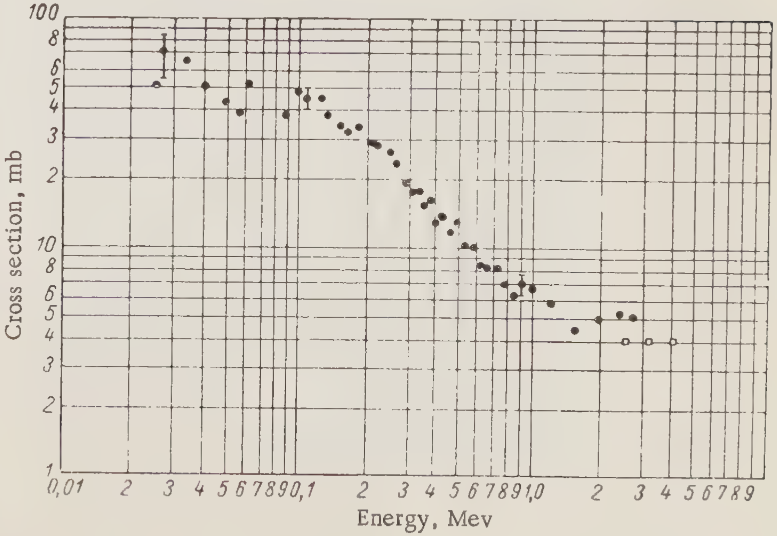

Fig. 4. Variation of the cross section for the radiative capture of fast neutrons by the Tl^{205} isotopes with neutron energy. Data from: ●-the present work; ◒-[1]; □-[11].

The authors thank Academician A. I. Leipunskii of the Academy of Sciences, UkrSSR and Dr. O. D. Kazachkovskii for their attention to this work and for valuable discussions.

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GAMMA RAYS PRODUCED BY INELASTIC SCATTERING OF 3-Mev NEUTRONS

A. L. Androsenko, D. D. Broder, and A. I. Lashuk

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Original article submitted July 17, 1960

Experiments on the study of γ-rays produced by the inelastic scattering of 3-Mev neutrons on titanium, chromium, strontium, iodine, tungsten, iridium, and bismuth nuclei were described in [1]. In the present communication we report the results obtained by the authors in a study of γ-rays produced by the inelastic scattering of neutrons on nuclei of boron, carbon, fluorine, sodium, magnesium, aluminum, silicon, phosphorus, sulfur, iron, cobalt, nickel, copper, zinc, selenium, zirconium niobium, molybdenum, cadmium, tin, antimony, lanthanum, tantalum, platinum, gold, and lead (see Table). Some of these elements were investigated in [2-8].

Gamma Rays Produced by the Inelastic Scattering of 3-Mev Neutrons

Element	γ-ray energy (Mev)	Element	γ-ray energy (Mev)
Boron	0,44±0,03 0,81±0,03 1,01±0,03 1,70±0,04	Phosphorus	1,00±0,03 1,23±0,03 2,06±0,04
Carbon	not obs.	Sulfur	1,25±0,03 1,82±0,04 2,14±0,04
Fluorine	(0,64±0,03) (0,81±0,03) 1,35±0,03* 1,86±0,04*	Iron	0,85±0,03 1,23±0,03 1,40±0,03 1,76±0,03
Sodium	0,44±0,04 1,70±0,03 1,96±0,04* 2,35±0,04	Cobalt	0,56±0,03 (0,87±0,03)* 1,20±0,03 1,49±0,03 1,79±0,04 2,48±0,04
Magnesium	0,33±0,03 0,58±0,03 0,94±0,03 1,35±0,03 1,82±0,04 2,75±0,04	Nickel	0,65±0,03 0,82±0,03 1,00±0,03* 1,39±0,03 1,96±0,04* 2,17±0,04
Aluminum	0,84±0,03 1,60±0,03 1,40±0,03 1,74±0,04 2,12±0,04	Copper	0,65±0,03 0,96±0,03 1,10±0,03 1,34±0,03 1,84±0,04
Silicon	1,04±0,03 1,72±0,03		

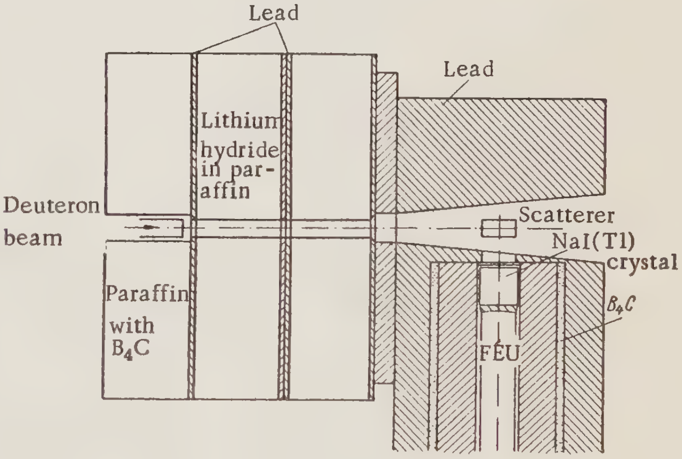

Fig. 1. Experimental arrangement.

The data on the γ-rays produced by inelastic scattering of 3-Mev neutrons on boron, silicon, platinum, and gold nuclei were obtain with the use of a "disk" geometry (Fig. 1). The deuterium target of the accelerator setup was surrounded by blocks of paraffin with an admixture of boron carbide. The neutron beam was collimated by a 20 mm dia aperture in blocks of paraffin containing lithium hydride. A 40 × 40 mm NaI(Tl) crystal and a photomultiplier were placed in a lead booth.

(continued)

Element	γ-ray energy (Mev)	Element	γ-ray energy (Mev)
Zinc	0,53±0,03* 0,81±0,03* 1,01±0,03 1,33±0,03 1,74±0,04 2,20±0,04*	Niobium	0,50±0,03 0,75±0,03 0,96±0,03 1,35±0,04*
Selenium	0,64±0,03* 0,84±0.03 1,04±0,04 1,26±0,04 1,72±0,04*	Molybdenum	0,54±0,03* 0,82±0,03 1,20±0,04 1,48±0,04
Zirconium	0,94±0,03 1,18±0,03 1,80±0,04 2,18±0,04	Cadmium	0,56±0,03 1,02±0,04* 1,42±0,04* 2,11±0,04
		Tin	0,86±0,03 1,20±0,04 1,75±0,04 2,06±0,04

(continued)

Element	γ-ray energy (Mev)	Element	γ-ray energy (Mev)
Antimony	0,49±0,03* 1,01±0,03 1,32±0,03 1,96±0,04	Platinum	0,53±0,03 0.85±0,03 1,15±0.03
Lanthanum*	0,87±0,03 1,21±0,04 1,78±0,04 2,17±0,04	Gold	0,23±0,03* 0.39±0,03* 0,84±0.03* 1.73±0.04
Tantalum	0,46±0,03 0,87±0,03* 1,18±0,04* 1,82±0.04*	Lead	0,52±0,03 0,79±0.03 1,05±0,03 1,37±0.03 2.64±0.04

Note: 1) The parentheses indicate γ-rays whose presence is in doubt. 2) The asterisk denotes lines not observed by other authors and those elements for which the γ-ray spectrum data (for inelastic scattering of neutrons) have not been published previously.

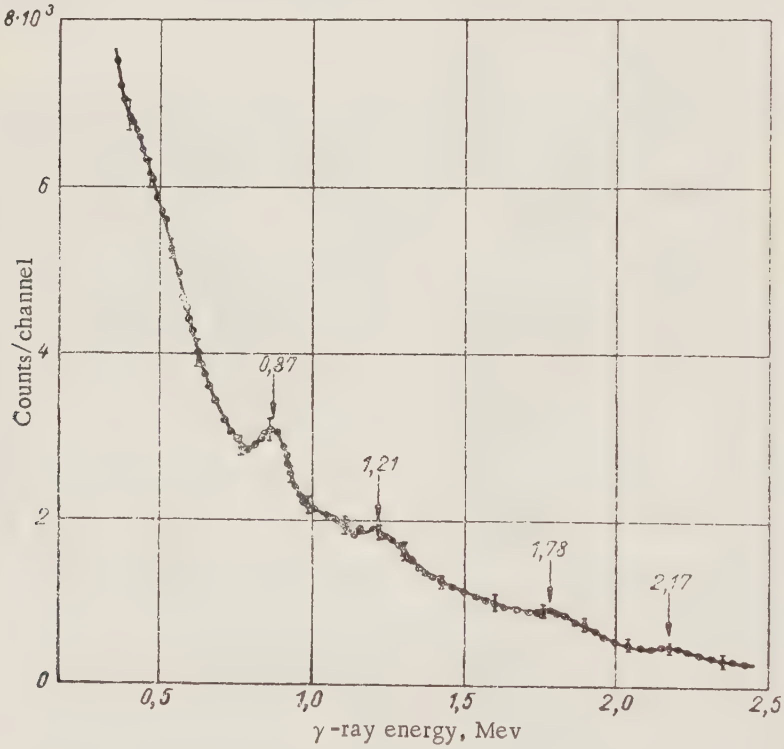

Fig. 2. Pulse spectrum from γ-rays produced by the inelastic scattering of 3-Mev neutrons in lanthanum.

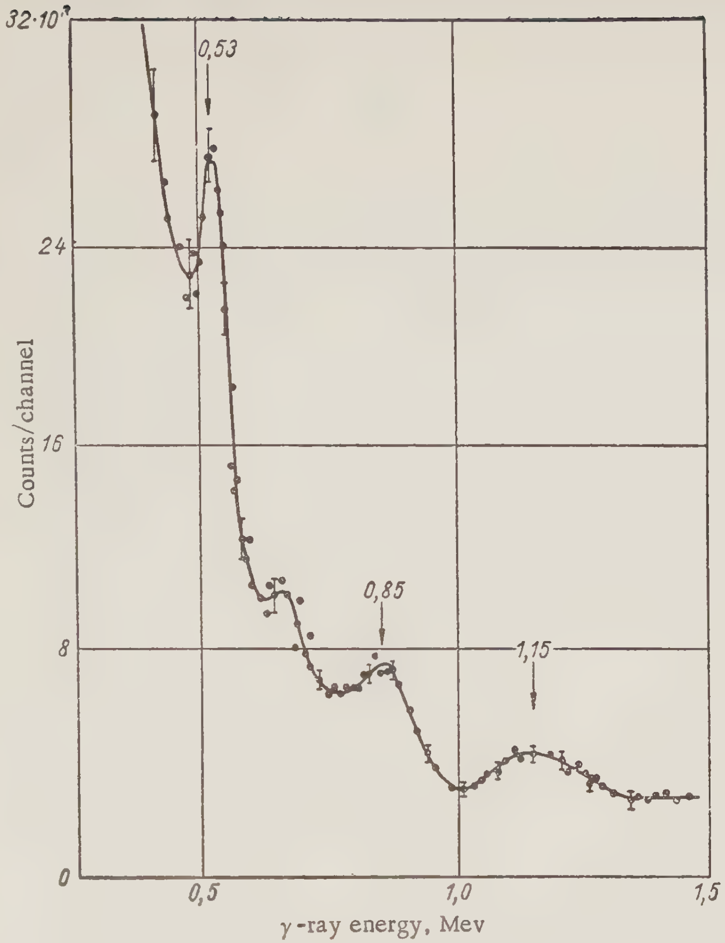

Fig. 3. Pulse spectrum from γ-rays produced by the inelastic scattering of 3-Mev neutrons in platinum.

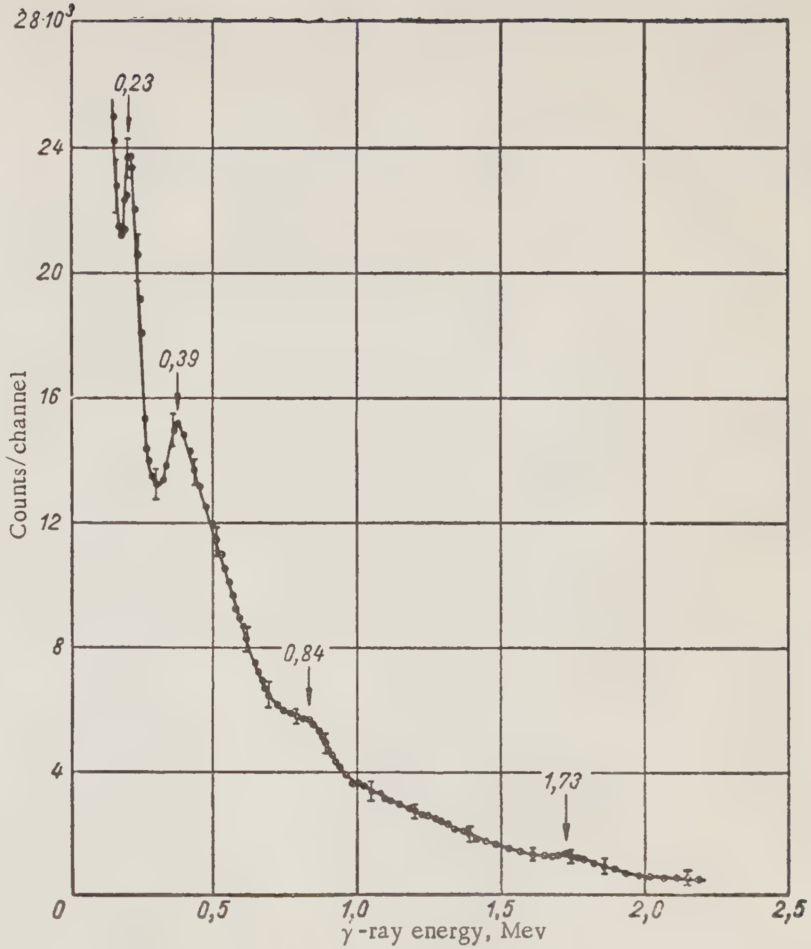

Fig. 4. Pulse spectrum from γ-rays produced by the inelastic scattering of 3-Mev neutrons in gold.

The investigated samples were mounted on a thin rod 4 cm from the crystal surface. To take into account the background, we used the results of the measurements with a carbon scatterer.

Figures 2-4 show the pulse spectra from γ-rays produced by the inelastic scattering of 3-Mev neutrons in lanthanum, platinum, and gold.

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PRODUCTION OF THICK LAYERS OF THORIUM, URANIUM, NEPTUNIUM, PLUTONIUM, AND AMERICIUM

G. I. Khlebnikov and E. P. Dergunov

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pp. 406-408, November, 1960
Original article submitted April 11, 1960

We studied methods of producing thick layers of some heavy elements by the methods of electrolytic precipitation, mechanical depositing with an addition of organic substances, electrochemical mixing, and the production of thick layers from suspension.

Electrochemical Method. The production of thick layers of some elements by a single electrolysis from organic (alcohol-acetone) and inorganic electrolytes (both acid and alkali) is very difficult, since, upon drying, the layers crack and crumble. We succeeded in producing thick layers (1 mg/cm^2 and thicker) by the method of multiple electrolytic precipitation on a single base.

Layers of thorium (Th^{230}) and ionium were obtained in the following way. We used an electrolytic apparatus of the ordinary type [1, 2]. For the cathode, we used 5 cm dia aluminum foil of thickness 50 μ and less, the fixed anode consisted of a coil of 0.5-1 mm platinum wire. The distance between electrodes was 2.5-3 cm. Crystals of thorium nitrate were dissolved by a few drops of distilled water. The solution was then diluted with 96% ethyl alcohol. Sixty cubic centimeters of this solution were used for the electrolysis. The influence of the cathode current density, thorium nitrate concentration, and electrolysis time on the amount of precipitated thorium (ThO_2) (Figs. 1 and 2) was studied. When the electroprecipitation was repeated under the same conditions, the increase in weight of the electrolytic precipitate was the same as before. After the completion of each run, the electrolyte was drawn off by a pipette; by means of a rubber bulb with a glass capillary tube, a weak stream of air was blown over the vessel for 20 min. The layer was then dried under a lamp (500 w) first at a distance of 15 cm (20 min) and then at 6 cm (15 min). This slow, gradual drying of the layer is a very important condition for the production of stable, thick layers. The entire operation of depositing and drying the layer was repeated several times. The amount of hydrated ThO_2 on the cathode was checked by periodically weighing the foil.

The stability of the layers was tested mechanically, by checking their weight and α activity. The uniformity of the large layers was checked by means of a photomultiplier with the use of various collimators. During the process of multiple electrolysis, the initial nonuniformity of the layer gradually disappeared.

The experiments indicated that sufficiently stable layers were not obtained for all current densities (see Fig. 1) and all initial concentrations (see Fig. 2). It is seen from Fig. 1 that with an increase in the cathode current density, for a constant concentration of thorium nitrate, the time for the production of an electrolytic precipitate of the greatest possible thickness decreases considerably. But the quality of the layers then rapidly becomes poorer.

An increase in the concentration of thorium nitrate in the electrolyte also has a negative effect on the mechanical properties of the electrolytic precipitate, although it decreases the number of deposits needed to produce the thick layers. The negative effect of increasing the thorium nitrate concentration on the quality of the layers is even stronger than in the case of an increase in the current density. The best layers were obtained for thorium nitrate concentrations of $c = 0.093$ mM and cathode current density of $i = 0.23$ ma/cm^2 and also for $c = 0.19$ mM ($i = 0.23$ ma/cm^2).

The technological procedure described for the preparation of thick layers is also convenient for the depositing of Np^{237} layers by electrolysis from an aqueous solution of a mixture of formic acid (0.5 M) and ammonium formate (0.5 M). Neptunium was precipitated on a platinum foil 5 μ thick with platinum as the fixed anode and i = 100 ma/cm^2. The remaining conditions for the electrolysis were the same as those used previously [3]. In each separate run, from 78 to 85% by weight of the quantity of neptunium used (~ 3 mg NpO_2) was deposited on the cathode. After a simple regeneration, the remaining neptunium was again used for the repeated electrolysis. In this way, we practically completely utilized the neptunium.

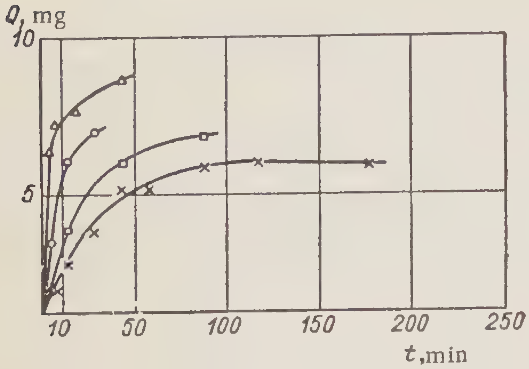

Fig. 1. Variation of the amount of thorium Q precipitated on the cathode with the electrolysis time t for a constant concentration of thorium nitrate in the electrolyte (c = 0.4 mM) and for different values of the cathode current density (ma/cm^2). Δ -4.6; O-0.92; □-0.46; × -0.23.

We obtained layers of neptunium 1-1.5 mg/cm^2 thick on an area of up to 20 cm^2 by the multiple precipitation method. The layers were sufficiently stable so as to permit subsequent depositing of neptunium on both sides of the base after a slight modification of the construction of the electrolyzer. The layers consisted of hydrated neptunium oxide (NpO_2xH_2O).

We also showed that layers could be deposited on both sides of an aluminum base in the case of thorium and ionium.

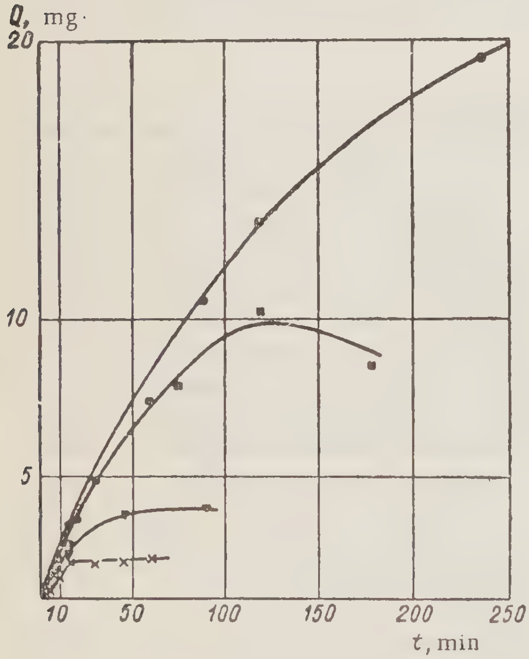

Fig. 2. Variation of the quantity of precipitate Q on the thorium cathode with the electrolysis time t for a constant cathode current density (i = 0.23 ma/cm^2) and for different thorium nitrate concentrations in the electrolyte (mM). ●-2; ■-0.76; ▼-0.19; ×-0.093.

Mechanical Depositing with Additions of Organic Substances. The method of producing layers with additions of organic substances—lacquers—has been used for some time in the preparation of thin, as well as thick, layers of uranium [4-6]. By means of this method, we produced layers 1-4 mg/cm^2 thick not only of uranium, but also of thorium, neptunium, plutonium, and americium on aluminum and platinum bases. In order to prevent losses, the layers were not deposited with a brush [4, 5], but with a glass capillary tube. The lacquers were prepared by dissolving nitrocellulose (2%) in amyl acetate; the resulting solution was diluted with acetone in the ratio 2:3. For other ratios, the obtained layers are uneven (greater thickness at the edges). In producing layers of thorium and uranium, it is desirable to keep the nitrate concentration in the solution no higher than 10-15 mg/ml, since at large concentrations there is a thickening of the layer at the edge of the target.

The nitrates were dissolved in a few drops of water, 0.5-2 ml of 96% ethyl alcohol was added, and while mixing, we added the amount of nitrocellulose chosen for the specific conditions of the run. The layers were multiply deposited; each time, we burned out the nitrocellulose. The stability of the layers obtained by this method of depositing on an aluminum base was high for U_3O_8, NpO_2 and low for PuO_2, AmO_2, ThO_2.

The uniformity of the layers depended on the amount of prepared solution, the number of deposits, the treatment of the base (it should be carefully degreased) and the quality of the first deposited layer; the successful depositing of the first layer is decisive for the good uniformity and stability of the subsequent layers.

Electrochemical Method. We also tried the electrochemical method described in 1953 in [7]. Sufficiently stable and thick layers were obtained by direct heating of an aluminum plate in an aqueous solution of uranyl nitrate.

We obtained layers of U_3O_8 of thickness 1-8 mg/cm^2 of over-all weight up to several tens of milligrams with a 50-80% utilization of uranium. The high stability of these layers was preserved up to thicknesses of 4 mg /cm^2. The stability of the layer basically depends on the initial pH factor of the uranyl nitrate solution (optimum value pH ≈ 3). In the case of solutions of greater acidity, the layers were loose. In the case of solutions of less acidity, aluminum hydroxide is deposited on the surface of the layer, which contaminates the layer and makes it less stable. If the solution contains an excessive amount of ammonia or aluminum salts, the stability of the layer becomes considerably poorer. The uniformity of the layer depends also on the care with which the base is treated [7].

Method of Precipitation from Suspension. Finally, we can indicate a sufficiently good method for producing thick layers (although not very stable) or radioactive samples, in particular, thorium, uranium, and the transuranium elements, by precipitation of compounds which are not readily soluble (for example, oxides) from finely suspended solutions in alcohols and mixtures of alcohol, ether, and acetone [4, 5]. These layers must be mounted. We used such a method to obtain layers of ThO_2 of thickness 1.2 mg/cm^2 on an aluminum base of area 20 cm^2. A finely pulverized suspension of ThO_2 in an alcohol-acetone solution was put inside a glass cylinder of an apparatus very much like the electrolytic cell. For several hours the greater part of the pure solution was carefully drawn off with a pipette, the layer was dried under a lamp, the entire apparatus was disassembled, the layer was given a final drying, annealed, and fixed with a few drops of a very dilute nitrocellulose solution (0.01 mg/cm^3) in acetone. The obtained layer was very uniform.

In conclusion, I consider it my duty to express my gratitude to Z. S. Gladkikh for aid in this work.

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A DEVICE FOR INVESTIGATING THE EFFECT OF γ-RADIATION ON SEMICONDUCTOR MATERIALS

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Original article submitted April 6, 1960

This article describes a cobalt device which was developed in 1958 at the Physicotechnical Institute, Academy of Sciences, USSR, for investigating the effect of γ-radiation on the electrical properties of semiconductors. The main purpose of such a device is to provide the possibility of producing stable lattice defects in various semiconductor materials. The production of such defects by means of γ-rays has definite advantages over other methods.

The requirements which must be satisfied in designing and constructing a device for the irradiation of semiconductors can be formulated in the following manner. Due to the fact that the cross section of the formation of defects by γ-rays in semiconductors is very small (for instance, for germanium, it is equal to only $4 \cdot 10^{-27}$ cm^2 [1]), very intensive γ-radiation fluxes of the order of 10^{11} cm^{-2} sec^{-1} are necessary for creating substantial defect concentrations, which, if standard Co^{60} sources are used, necessitates the placement of the specimens to be irradiated in accurately fixed positions in the immediate vicinity of the source. In this, if a single source is used, the irradiated specimen dimensions must be small if a uniform distribution of defects throughout the volume is to be obtained. For the investigation of processes connected with induced conductivity, the device must provide the possibility of varying the γ-radiation incident to the specimen within a very wide range. The last important requirement is the provision for complete safety of the technicians entrusted with mounting and servicing the device. Moreover, we strived to produce a simple and efficient design.

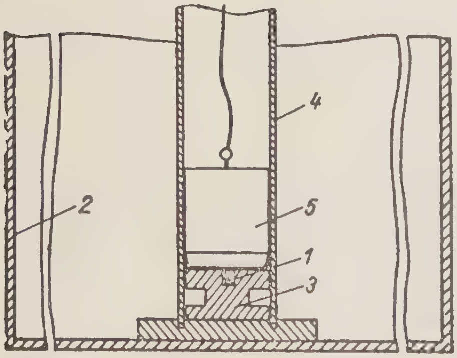

Fig. 1. Diagram of the device.

These requirements are satisfied by the device whose design is schematically shown in Fig. 1. A standard Co^{60} source, 1, which had an activity of 400 g-eq Ra, was placed at the bottom of a welded iron tank, 2, whose height was 2.9 m and which was filled to the top with water. The tank, which was covered with bitumen on the outside, was set into sandy ground so that its upper end was flush with the room floor. The tank dimensions were 2.5 × 0.6 × 2.9 m, and the wall thickness was 5 mm. The source was placed in a special recess of a brass block, 3. A copper tube, 4, which had an inside diameter of 125 mm, through which chamber 5 with the specimens was lowered to the source, was fitted on the block (see also Fig. 2). The tube was also filled with water. The conical end of the chamber fitted into the corresponding opening in the block, whereby the specimens, which were mounted inside the chamber on a rigid holder, were accurately placed with respect to the source. If the specimens had to be located at a spot where the dose rate was different from its maximum value, the chamber was lifted to a fixed height above the block by means of interchangeable conical fittings 9 (see Fig. 2). In order to prevent the chamber rotation, its lid was provided with a guiding projection, 10, which moved along a longitudinal groove in the tube. Besides the central tube, which was placed directly above the source, several other tubes with smaller diameters were placed in the tank. These tubes were used for irradiation with intensities considerably lower than that in the central tube.

The unloading of the source from the container, which was performed under water, was perfectly safe for the operators. A special lid opener and remote-handling tools (tongues, an electromagnet, socket wrenches, etc.) were used for removing the source from its socket in the transport container lid and for placing it into the block recess.

Dose Rate at Different Locations in Chamber, r/sec

Distance	Chamber bottom	10 mm from bottom	20 mm from bottom	40 mm from bottom
Chamber center	128	72	43	22
15 mm from center	124	70	42	21
22 mm from center	91	61	39	20
30 mm from center	69	50	35	19

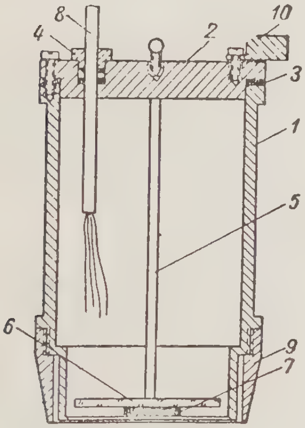

Fig. 2. Diagram of the specimen chamber.

The specimen chamber (see Fig. 2) consisted of a brass shell, 1, with a lid, 2, which was fastened to the shell by means of bolts. A ring-shaped rubber gasket, 3, was provided between the lid and the shell for preventing the water from penetrating the chamber. Through a hermetically sealed leadin, 4, which was mounted on lid 2, a multiconductor cable, 8, was introduced into the chamber, which made it possible to measure the electrical parameters of the irradiated specimens. Holder 6, on which specimens 7 were placed, was rigidly fixed inside the chamber by means of two braces, 5. Asbestos-cement was used as the material for the specimen holder. The γ-radiation attenuation due to the chamber bottom, which was 2 mm thick, was negligible.

Besides the chamber shown in Fig. 2, other chamber types were used. For instance, one of the chambers was designed for cooling specimens by means of dry ice. Carbon dioxide, which evolved during dry ice evaporation, was released from the chamber by means of a rubber valve, which prevented the inleakage of water into the chamber. The same chamber was also used for measurements at higher temperatures; for this a miniature nichrome-wire heater was used.

The γ-radiation intensity distribution at the different possible places where the specimens could be located was measured according to the chemical method, which is based on the reaction of conversion of bivalent iron in the $FeSO_4$ compound into trivalent iron, which occurs when a solution of this salt is irradiated by γ-rays [2]. For this purpose, a number of annular glass jars with a Mohr's salt solution were placed on the bottom of the main chamber. In this, the γ-field along the chamber diameter and height was measured. In order to verify the data which we obtained by using the chemical method, we performed simultaneous dose rate measurements using a different method. For this purpose, the Mohr's salt solution was exposed to prolonged irradiation at a spot where the dose rate amounted to only 100 r/hr; at the same spot, the dose rate was also measured by means of a dosimeter. The discrepancies between the results obtained in using these two methods were within the measurement accuracy limits (10%). The results obtained in measuring the dose rate are given in the table, from which it is obvious that the γ-radiation intensity sharply decreases already at a distance of 30-40 mm from the source; however, for the irradiation of small-size specimens, the obtained γ-radiation intensity distribution can be considered as satisfactory.

After the device had been in operation over a period of 8 months, it was demounted for the purpose of investigating the tank state near the source. No noticeable damage to the tank inside surface was detected. Thus, on the basis of the available data, it can be considered that the described device is entirely suitable for investigating problems connected with the effect of γ-radiation on semiconductors.

The authors hereby express their gratitude to L. V. Maslova for her help in measuring the γ-field distribution.

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MEASUREMENT OF THE ULTRASOUND VELOCITY IN MOLTEN ALKALI METALS

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Original article submitted June 22, 1960

There are almost no literature data on the velocity of sound in molten alkali metals. The data from [1], obtained for sodium and potassium at the melting temperature, contain a large systematic error.

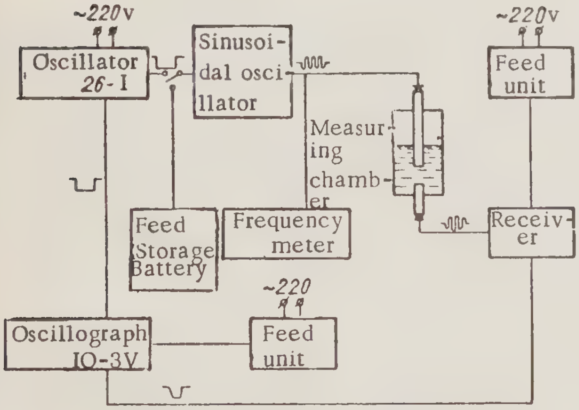

Fig. 1. Block diagram of the device.

We measured the velocity of ultrasound in sodium and in eutectic Na – K at temperatures of up to 700°C by using the pulse interferometer method (Fig. 1).

Square pulses with negative polarity, which are supplied by a 26-I oscillator, trigger the radio pulse generator and the scanning of the IO-3V pulse oscillograph. The radio pulses, which have a duration $\tau = 10\,\mu$ sec and a carrier frequency of 2 Mc, are fed to an X-cut quartz plate, which is installed on the upper acoustic lag line; the latter can be smoothly moved along the vertical. After passing through the upper lag line, the molten metal, and the lower lag line, the ultrasound wave trains are received and transformed by the quartz plate located on the lower acoustic lag line. From the quartz plate, the signals are fed to the input of a receiver which is based on a superheterodyne cir-

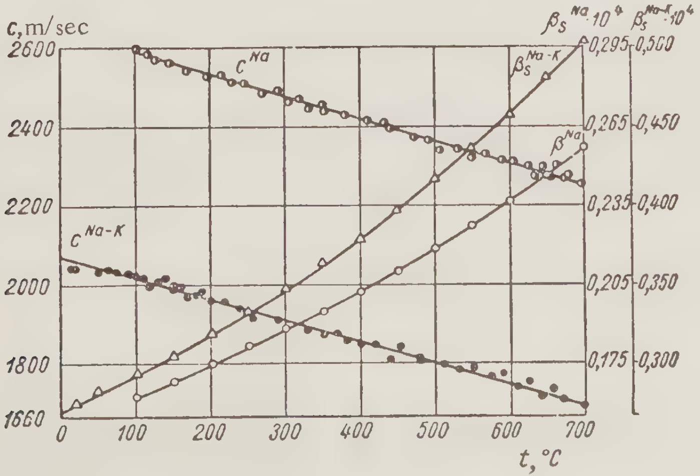

Fig. 2. Velocity of sound and the adiabatic compressibility of sodium and eutectic Na – K.

cuit with an intermediate frequency of 16 Mc. In the amplifier channel, the pulses are detected, and the amplified video pulses are fed to the input of a pulse oscillograph. The acoustical path length traveled by the signal through the medium under investigation is varied by gradually moving the mobile acoustic lag line. For sufficiently small distances between the end-faces of the acoustic lag lines, when the condition

$$\tau \geq \frac{2l}{c} \tag{1}$$

is satisfied (τ is the pulse duration, l is the distance between the end-faces of the acoustic lag lines, and c is the velocity of sound in the medium), the reflected signal interferes with the direct signal. If the mobile acoustic lag line is periodically moved through a distance equal to $\lambda/2$, oscillation nodes and loops are formed at the end-faces, which makes it possible to observe the signal amplitude variation on the oscillograph screen. The ultrasound wavelength λ is determined by moving the lag line through a distance of $(13\text{-}17)\lambda/2$ and by measuring the distance between its two positions. For accurate measurement and control of the device frequency, an arrangement is provided for switching the generator of radio pulses to continuous-operation conditions by supplying a negative bias to the oscillator input. The radio pulse carrier frequency was measured by means of a type-526 heterodyne wavemeter. The sound velocity was calculated according to the equation

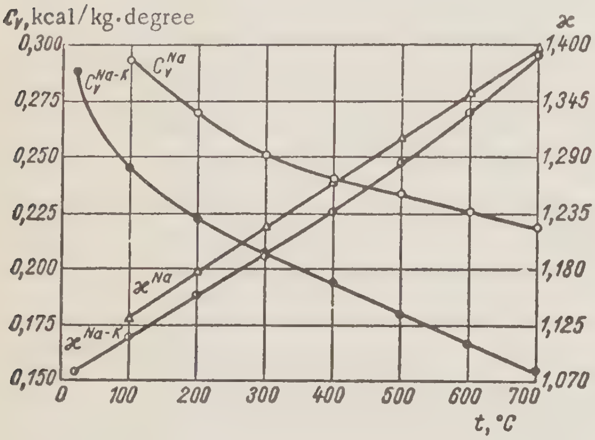

Fig. 3. Ratio of specific heats $\varkappa = (C_p/C_V)$ and the values of C_V for sodium and eutectic Na – K.

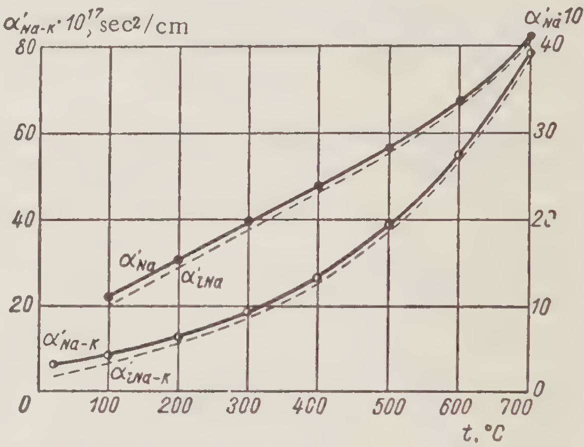

Fig. 4. Sound absorption coefficient α' and α_l' which are independent of the frequency.

$$c = f\lambda \tag{2}$$

where f is the radio pulse carrier frequency, and λ is the wavelength.

The described method for measuring the sound velocity is free from systematic errors; calibration experiments with water indicated that the obtained results are in good agreement with the available literature data [2].

Figure 2 shows the results obtained in measuring the velocity of sound in sodium and eutectic Na – K (25% Na + 75% K), which indicate that the velocity of sound in molten alkali metals at temperatures of up to 700°C (as well as in a large group of normal liquids whose state is far removed from the critical point) linearly decreases with an increase in temperature. The analytical dependence of the sound velocity on temperature can be expressed by the relations

$$c^{Na} = 2594 - 0.577\,(t - 100); \tag{3}$$

$$c^{Na-K} = 2070 - 0.543t, \tag{4}$$

where c^{Na} and c^{Na-K} are the velocities of sound in sodium and eutectic Na – K (m/sec), and t is the temperature of the medium under investigation (°C). The maximum measurement error did not exceed 1.8%.

On the basis of the obtained data on the sound velocity and the tabular data on density, specific heat for P = const, viscosity, and thermal conductivity [3], we calculated the adiabatic compressibility β_s (1/atm), the ratio of specific heats for constant pressure and volume $\varkappa = C_P/C_V$, the specific heat C_V (kcal/kg · °C), and the sound absorption coefficient which is independent of frequency α' (sec^2/cm) by using the equations

$$\beta_s = \frac{1}{\varrho c^2}; \tag{5}$$

$$\varkappa = 1 + \frac{T\alpha^2 c^2}{JC_p}; \tag{6}$$

$$\alpha' = \alpha'_r + \alpha'_l = \frac{2\pi^2}{c^3\varrho}\left(\frac{4}{3}\eta + \frac{\varkappa-1}{C_p}\lambda\right), \tag{7}$$

where ρ is the density, T is the absolute temperature, J is the mechanical equivalent of heat, equal to 4.186×10^7 erg/cal, α is the thermal expansion coefficient, C_P is the specific heat for P = const, η is the viscosity coefficient, λ is the thermal conductivity coefficient, and α'_r and α'_l are the coefficients of sound absorption due to viscous friction and the molten metal thermal conductivity, respectively. The dependences of the calculated values on temperature are shown in Figs. 2-4.

For the $\varkappa$ and C_V quantities as well as for the velocity of sound it is characteristic that they change linearly in a wide temperature range: $\varkappa^{Na}$ changes linearly in the interval from 100 to 700°C, and $\varkappa^{Na-K}$ changes in the interval from 20 to 400°C; C_V^{Na} and C_V^{Na-K}, on the contrary, change linearly only in the region of higher temperatures, from 400 to 700°C and from 250 to 700°C, respectively. Calculations show that the absorption of sound in molten alkali metals, for which the ratio of the thermal conductivity coefficient to the viscosity coefficient is higher by two orders of magnitude than for water, acetone, and other normal liquids, primarily depends on the thermal conductivity. The contribution of α'_r to the absorption coefficient at 100 and 700°C is equal to 10 and 1.3% for sodium and 23 and 1.5% for eutectic Na–K, respectively.

In performing the experiments, it was also found that, by using ultrasound, the wettability of structural materials in alkali metals can be determined in a simple and reliable manner.

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THE RADIATION-CHEMICAL CHLORINATION OF BENZENE

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The radiation chlorination of benzene was studied in connection with the use of nuclear radiations in the preparation of hexachlorane. The specific action of different types of radiation in the initiation of the reaction was determined by chlorinating benzene under standard conditions. The use of radiations of different energy, as can be seen from the table, led to the preparation of hexachlorocyclohexane (HCCH), differing considerably in the α-isomer content.

The Effect of Various Types of Initiation on the Isomer Composition of Hexachlorocyclohexane

Initiation	Concentration of chlorine, 1 g per 100 g benzene	t, °C	Dose rate, rad/sec	Dose, rad	Content of γ-isomer, %	Content of α-isomer, %	Mean energy, ev
Thermal	62.1	100	–	–	No data	No data	–
Chemical (benzene peroxide)	14.0	40	–	–	12.7	63.7	–
Infrared radiation	14.0	40	–	–	12.7	67.0	0.01
Ultraviolet radiation	14.0	40	–	–	11.3	73.8	3–5
β-radiation	14.0	40	3.48	$2.4 \cdot 10^4$	10.2	78.5	$0.4 \cdot 10^6$
γ-radiation	14.0	40	6.75	$2.4 \cdot 10^4$	11.8	83.5	$1.2 \cdot 10^6 - 1.3 \cdot 10^6$

With increase in the energy of radiation the content of the α-isomer increased from 63.7 to 83.5%, whereas the content of the γ-isomer hardly changed at all. The change in the isomer composition of the chlorination products when the reaction is initiated with high energy radiation is due to the fact that benzene takes part in the reaction not only as the reagent but also as the solvent, efficiently transmitting the absorbed energy. Under conditions of radiation chlorination of benzene energy can be transmitted from excited molecules of benzene to molecules of the dissolved substance – the intermediate products in the chlorination of benzene. Since these products can contain different amounts of the stereoisomers, the energy of formation of which differ very little [1], the additional energy action can cause isomerization of the intermediate products, which affects the isomer composition of the HCCH.

Due to the high penetrating capacity of the ionizing radiations, initiating centers are formed throughout the whole volume of the reaction mixture, whereas ultraviolet radiation is completely "extinguished" in an 18 mm layer of the benzene solution of chlorine [2] and the chain reaction in the whole of the volume is only propagated by diffusion of the chlorine atoms. When using β-radiation (mean energy 0.4 Mev) the content of the α-isomer depends on the thickness of the irradiated layer. Thus, in a 5 mm layer the content of the α-isomer is 78.5%, and in a 40 mm layer it falls to 61%.

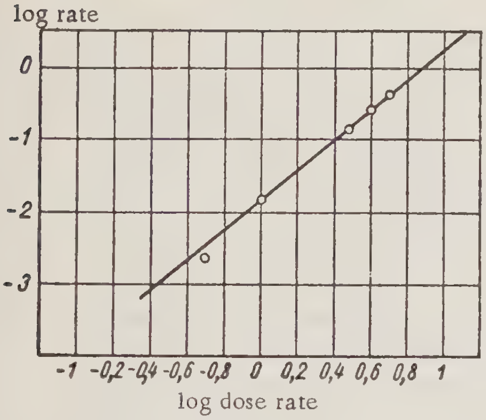

Fig. 1. Dependence of the reaction rate on the intensity of radiation.

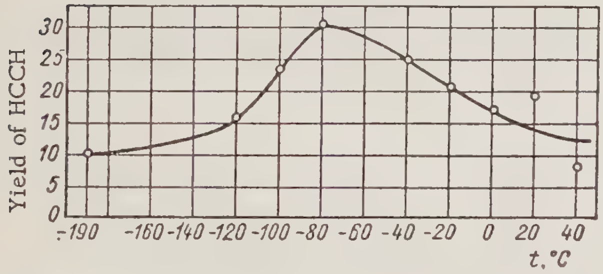

Fig. 2. Effect of temperature on the yield of chlorination products.

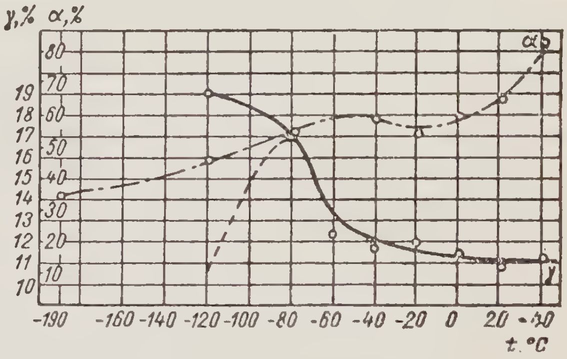

Fig. 3. The effect of chlorination temperature on the isomer composition of hexachlorocyclohexane.

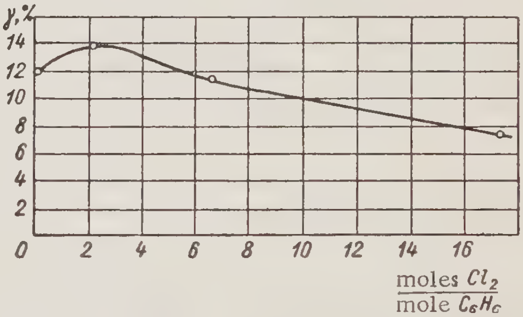

Fig. 4. The effect of chlorine concentration on the content of the γ-isomer.

In the chlorination of the α-isomer of tetrachlorocyclohexene (one of the intermediate products in the chlorination of benzene) the use of a different kind of radiation (ultraviolet, infrared, β(Sr^{90}), γ(Co^{60}) resulted in a product with the same isomer composition. This is possibly due to the fact that the chlorination was carried out in a CCl_4 solution, which is a poor transmitter of energy.

When it is initiated by ionizing radiations, the chlorination of benzene proceeds extremely intensely, with a high energy yield. The radiation-chemical yield of the reaction reaches 853,000 per 100 ev. However, the value of G depends to a large extent on the purity of the initial products and when commercial benzene is used it drops to 130,000. The maximum radiation-chemical yield when using ultraviolet radiation (wavelength 3,650 A) is about 9,000 molecules per 100 ev.

The reaction rates in the radiation chlorination of benzene (in contrast to many photochemical chain reactions) are proportional to the square of the intensity of the radiation (Fig. 1). This dependence is observed when benzene is chlorinated without a solvent in the range of dose rates of 0.5-5 rad/sec. Dilution of the benzene with carbon tetrachloride or other solvents considerably lowers the rate of reaction.

The chlorination of benzene with initiation by ionizing radiations in the temperature range 10-40°C is a first order reaction (with regard to chlorine). The constant for the reaction rate at a dose rate of 5 rad/sec is 0.0115. With change in the dose rate the constant of the reaction rate is inversely proportional to the square of the intensity of radiation. The temperature coefficient of the reaction in the temperature range 10-40°C is almost equal to unity.

In contrast to the photochemical chlorination, the radiation chlorination of benzene can take place at very low temperatures in the solid phase. The yield of chlorination products increases (Fig. 2) with reduction in temperature to −80° (with the same concentrations of chlorine, dose rates and doses of absorbed energy).

In the temperature range 40 to −80°C a product is formed containing 97-99% of the total of HCCH isomers. At lower temperature of −120°C the tetrachlorocyclohexene content reaches 58%.

Changes in chlorination temperature affect the isomer composition of the HCCH (Fig. 3). With reduction in temperature to −80°C the content of the γ-isomer increases to 17-18%. With further reduction in temperature the total content of the γ-isomer falls since a large quantity of tetrachlorocyclohexene forms; however with respect to the HCCH which is formed the yield of the γ-isomer is 18-19%. The content of the α-isomer with reduction in temperature from 40 to −190°C is reduced from 83.5 to 38%. The content of the γ-isomer of HCCH also depends on the chlorine concentration (Fig. 4).

An analysis of literature and experimental data shows that the content of the γ-isomer in hexachlorane depends relatively little on the methods for preparing the hexachlorane and is mainly determined by the isomer transformations of the intermediate chlorination products. On this basis we considered a scheme of isomer transformations of the intermediate products of benzene chlorination which was used to calculate the probability of the formation of α-, β-, γ-, δ-, ϵ-isomers of HCCH taking into account their energy of formation; the probabilities of the formation of these isomers are 27.8; 4.63; 25.0; 26.0; and 16.7%.

The reduced content of the γ-isomer in the commercial product is due to the transformation of the γ-isomer into the α-isomer occurring during the chlorination of benzene. The rate of transformation of the γ- to the α-isomer is reduced with reduction in temperature, therefore in the region of low temperatures a product is formed with a higher content of the γ-isomer (up to 18%). The transformation of the γ- to the α-isomer is only observed in the chlorination of the γ-isomer in benzene solution. In the chlorination of a solution of the γ-isomer in CCl_4 no isomerization takes place.

A study of the chlorination of benzene under the action of ionizing radiations showed that the radiation-chemical method has some advantages over the photochemical process, despite the fact that the chlorination products do not differ from one another in their content of the γ-isomer. Ionizing radiations can give a product with a high content of the α-isomer (up to 83%). The obtained product is therefore almost a two-component system, the separation of which does not present any particular difficulties, which is important in the production of enriched HCCH. This eliminates the need for a special solvent to extract the γ-isomer and the use of a benzene mother liquor for this purpose.

Since the content of the total of HCCH isomers in the chlorination products is 97-99%, the hexachlorane has a much less unpleasant odor. The high penetrating capacity of ionizing radiations and the high radiation-chemical yield means that the chlorination can be carried out in small-diameter metal tubes with external radiation. This means that the heat removal can be improved and the productivity of the reactor can be increased with a considerable reduction in dimensions. The consumption of electrical power is then reduced.

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THE THERMODYNAMICS OF THE REDUCTION OF POTASSIUM AND SODIUM FLUORIDES BY METALLIC CALCIUM AND MAGNESIUM

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Uranium tetrafluoride sometimes contains a certain amount of contaminating sodium and potassium, principally in the form of fluorides. These fluorides can interact with the calcium or magnesium which is used as the reducing agent, disturbing the normal course of melt reduction and diminishing the yield of metal in the ingot. Thermodynamic calculations have been carried out on the reactions of sodium and potassium fluorides with calcium

Basic Thermodynamic Quantities

Thermodynamic quantity and units	Reaction component	Value of thermodynamic quantity	Literature	Heat capacity, C_p cal/(mole × °C)	Temperature interval for C_p, °K	Literature for C_p
ΔF^0_{298}, kcal/mole	NaF	—129,3	[2]	—	—	—
ΔF^0_{298}, » »	KF	—127,4	[5]	—	—	—
ΔF^0_{298}, » »	CaF_2	—277,7	[2]	—	—	—
ΔH^0_{298}, kcal/mole	NaF	—136,0	[2]	—	—	—
ΔH^0_{298}, » »	KF	—134,5	[5]	—	—	—
ΔH^0_{298}, » »	CaF_2	—290,3	[2]	—	—	—
ΔS^0_{298}, kcal/(mole · deg)	NaF	14,0	[3]	$10{,}79+4{,}2\cdot10^{-3}T$	273—1265	[4]
ΔS^0_{298}, » » »	KF	15,91	[3]	$11{,}27+3{,}86\cdot10^{-3}T-0{,}69\cdot10^{5}\cdot T^{-2}$	330—530	[4]
ΔS^0_{298}, » » »	CaF_2	16,46	[3]	$13{,}8+7{,}8\cdot10^{-3}T$	298—1424	[4]
ΔS^0_{298}, » » »	Na	12,2	[3]	$5{,}01+5{,}36\cdot10^{-3}T$	298—371	[4]
ΔS^0_{298}, » » »	K	15,2	[3]	$5{,}24+5{,}55\cdot10^{-3}T$	273—336,5	[4]
ΔS^0_{298}, » » »	Ca	9,95	[3]	$5{,}31+3{,}33\cdot10^{-3}T$	273—713	[4]
ΔH_t, kcal/mole	α Ca → β Ca	0,24	[4]	$1{,}5+7{,}74\cdot10^{-3}T+2{,}5\cdot10^{5}\cdot T^{-2}$	750—1123	[4]
ΔH_t, » »	α CaF_2 → β CaF_2	1,14	[3]	$25{,}81+2{,}5\cdot10^{-3}T$	1424—1691	[4]
ΔH_{mp}, kcal/mole	NaF	7,8	[4]	16,0	>1256	[5]
ΔH_{mp}, » »	KF	6,3	[4]	16,7	>1159	[5]
ΔH_{mp}, » »	CaF_2	7,1	[3]	23,88	1691—1800	[4]
ΔH_{mp}, » »	Na	0,63	[4]	7,5	371—450	[4]
ΔH_{mp}, » »	K	0,57	[4]	7,7	336,5—373	[4]
ΔH_{mp}, » »	Ca	2,2	[3]	7,4	1123—1223	[4]
ΔH_{evap}, kcal/mole	Na	23,4	[4]	4,97	>1156	[3]
ΔH_{evap}, » »	K	19,0	[4]	4,97	>1048	[3]
ΔH_{evap}, » »	Ca	34,8	[6]	4,97	1713	[3]

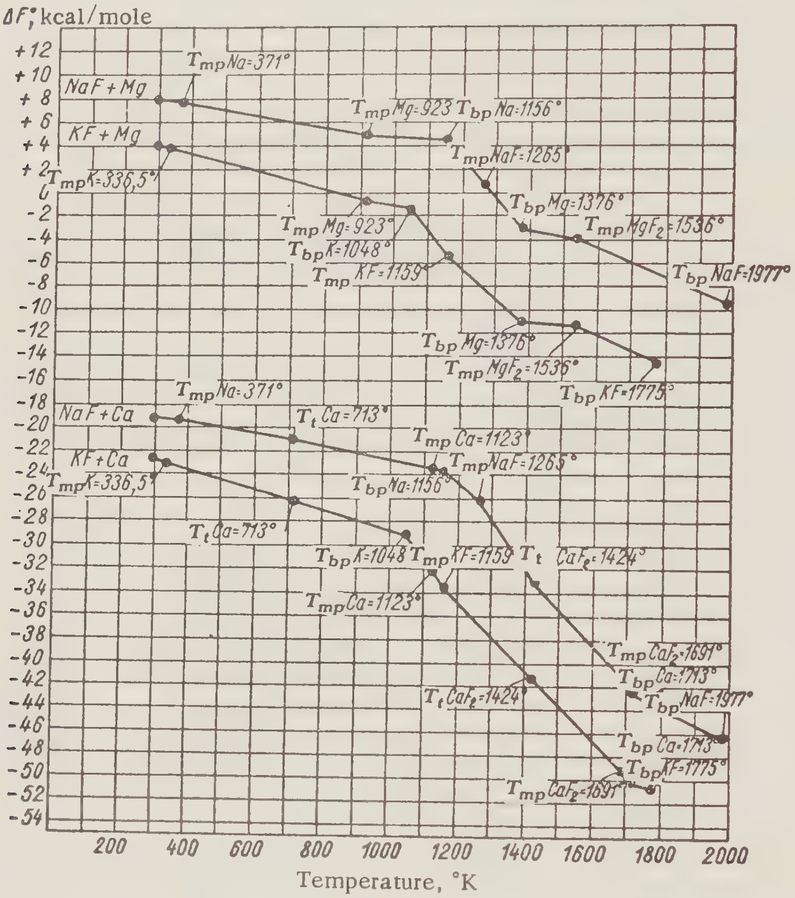
Notes: 1. The entropy change accompanying phase transformation of the reaction component was calculated from the equation $\Delta S_t=(\Delta H_t)/T_t$. 2. The thermodynamic data on magnesium and MgF_2 have been presented in [1].

$$2NaF + Ca \rightleftarrows 2Na + CaF_2;$$
$$2KF + Ca \rightleftarrows 2K + CaF_2$$

and with magnesium

$$2NaF + Mg \rightleftarrows 2Na + MgF_2;$$
$$2KF + Mg \rightleftarrows 2K + MgF_2.$$

in order to elucidate the behavior of these contaminating alkali metals during reduction of molten uranium tetrafluoride by the method described in [1].



The temperature dependence of the free energy change in the reactions of sodium and potassium fluorides with magnesium and calcium.

The data of Table 1 were used in these calculations.

Calculated values of the change in the thermodynamic potential of each of these systems, ΔF°_{T}, over various temperature intervals are presented in Table 2.

The broken line curves of the figure were developed from the equations of Table 2 and show the temperature dependence of ΔF°_{T}. These curves indicate that it is thermodynamically possible for magnesium and, especially calcium, to reduce sodium and potassium fluorides to the metals at the temperatures required for thermal reduction of uranium tetrafluoride (theoretical temperatures: 2200 and 1263°C, respectively [7]; actual temperatures: 1700-1750°C [8]), the potassium compound being reduced more readily than the sodium. Sodium and potassium boil at 883 and 775°C, respectively [4]. Thus vapors of these metals can eject fusion products from the

TABLE 2

ΔF°_T for the Reduction of Sodium and Potassium Fluorides by Calcium and Magnesium

Temperature interval °K	ΔF°_T, cal/mole
	$2NaF + Ca = 2Na + CaF_2$
298—371	$-17\,690 - 21{,}4T - 3{,}4 \cdot 10^{-3}T^2 + 7{,}06T \lg T$
371—713	$-17\,540 + 5{,}64T + 1{,}97 \cdot 10^{-3}T^2 - 4{,}39T \lg T$
713—1123	$-19\,730 + 31{,}9T + 4{,}17 \cdot 10^{-3}T^2 + 1{,}25 \cdot 10^5 T^{-1} - 13{,}14T \lg T$
1123—1156	$-19\,820 - 5{,}07T + 0{,}3 \cdot 10^{-3}T^2 + 0{,}43T \lg T$
1156—1265	$32\,840 - 86{,}29T + 0{,}3 \cdot 10^{-3}T^2 + 12{,}08T \lg T$
1265—1424	$23\,700 - 148{,}1T - 3{,}9 \cdot 10^{-3}T^2 + 36{,}05T \lg T$
1424—1691	$13\,100 - 57{,}48T - 1{,}25 \cdot 10^{-3}T^2 + 8{,}42T \lg T$
1691—1713	$27\,010 - 82{,}13T + 12{,}86T \lg T$
1713—1977	$-11\,960 - 41{,}3T + 7{,}26T \lg T$
	$2KF + Ca = 2K + CaF_2$
298—336,5	$-20\,200 - 27{,}39T - 3{,}93 \cdot 10^{-3}T^2 - 0{,}69 \cdot 10^5 T^{-1} + 8{,}2T \lg T$
336,5—713	$-20\,090 - 1{,}1T + 1{,}63 \cdot 10^{-3}T^2 - 0{,}69 \cdot 10^5 \cdot T^{-1} - 3{,}1T \lg T$
713—1048	$-22\,280 + 25{,}16T + 3{,}83 \cdot 10^{-3}T^2 + 0{,}56 \cdot 10^5 \cdot T^{-1} - 11{,}85T \lg T$
1048—1123	$21\,440 - 54{,}3T + 3{,}83 \cdot 10^{-3}T^2 + 0{,}56 \cdot 10^5 \cdot T^{-1} + 0{,}75T \lg T$
1123—1159	$21\,350 - 91{,}27T - 0{,}04 \cdot 10^{-3}T^2 - 0{,}69 \cdot 10^{-5} \cdot T^{-1} + 14{,}32T \lg T$
1159—1424	$16\,060 - 158{,}63T - 3{,}9 \cdot 10^{-3}T^2 + 39{,}32T \lg T$
1424—1691	$5460 - 68{,}02T - 1{,}25 \cdot 10^{-3}T^2 + 11{,}7T \lg T$
1691—1713	$19\,370 - 92{,}67T + 16{,}14T \lg T$
1713—1775	$-19\,600 - 51{,}84T + 10{,}54T \lg T$
	$2NaF + Mg = 2Na + MgF_2$
298—371	$7530 - 0{,}18T - 1{,}29 \cdot 10^{-3}T^2 + 1{,}28 \cdot 10^{-5}T^{-1} + 0{,}02T \lg T$
371—923	$7680 + 26{,}86T + 4{,}08 \cdot 10^{-3}T^2 + 1{,}28 \cdot 10^5 \cdot T^{-1} - 11{,}43T \lg T$
923—1156	$7180 + 9{,}61T + 2{,}85 \cdot 10^{-3}T^2 + 1{,}33 \cdot 10^5 \cdot T^{-1} - 5{,}06T \lg T$
1156—1265	$59\,830 - 71{,}61T + 2{,}85 \cdot 10^{-3}T^2 + 1{,}33 \cdot 10^5 T^{-1} + 6{,}6T \lg T$
1265—1376	$50\,690 - 133{,}41T - 1{,}35 \cdot 10^{-3}T^2 + 1{,}33 \cdot 10^5 \cdot T^{-1} + 30{,}56T \lg T$
1376—1536	$14\,520 - 85{,}12T - 1{,}35 \cdot 10^{-3}T^2 + 1{,}33 \cdot 10^5 \cdot T^{-1} + 23{,}56T \lg T$
1536—1977	$23\,040 - 50{,}98T + 10{,}47T \lg T$
	$2KF + Mg = 2K + MgF_2$
298—336,5	$5020 - 6{,}17T - 1{,}82 \cdot 10^{-3}T^2 + 0{,}59 \cdot 10^5 \cdot T^{-1} + 1{,}17T \lg T$
336,5—923	$5120 + 20{,}12T + 3{,}74 \cdot 10^{-3}T^2 + 0{,}59 \cdot 10^5 \cdot T^{-1} - 10{,}13T \lg T$
923—1048	$4630 + 2{,}87T + 2{,}51 \cdot 10^{-3}T^2 + 0{,}64 \cdot 10^5 \cdot T^{-1} - 3{,}76T \lg T$
1048—1159	$48\,350 - 76{,}59T + 2{,}51 \cdot 10^{-3}T^2 + 0{,}64 \cdot 10^5 \cdot T^{-1} + 8{,}85T \lg T$
1159—1376	$43\,060 - 143{,}95T - 1{,}35 \cdot 10^{-3}T^2 + 1{,}33 \cdot 10^5 \cdot T^{-1} + 33{,}85T \lg T$
1376—1536	$6880 - 95{,}66T - 1{,}35 \cdot 10^{-3}T^2 + 1{,}33 \cdot 10^5 \cdot T^{-1} + 26{,}85T \lg T$
1536—1775	$15\,400 - 61{,}52T + 13{,}76T \lg T$

system at the temperature of thermal reduction of uranium tetrafluoride by calcium and can increase the pressure in the closed system during thermal reduction by magnesium. The alkali metal content of the uranium tetrafluoride must be carefully controlled if these undesirable effects are to be avoided.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

NEWS OF SCIENCE AND TECHNOLOGY

THE INTERNATIONAL CONGRESS ON AUTOMATIC CONTROL

I. Emel'yanov

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The First International Congress for Automatic Control was held in Moscow June 27-July 2, 1960 in the buildings of Moscow State University. The USSR National Committee on Automatic Control handled the organization of the Congress, in accordance with a resolution of the General Assembly of the International Federation of Automatic Control (IFAC).

More than 1100 delegates from 29 countries were present at the Congress. The Congress was opened by Professor A. M. Letov, President of the IFAC, A. N. Kosygin, First Vice-Chairman of the USSR Council of Ministers, welcomed the delegates and guests of the Congress on behalf of the Soviet government. Academician A. N. Nesmeyanov, President of the USSR Academy of Sciences, also expressed greetings.

On the opening day of the Congress the chairman of the USSR National Committee on Automatic Control, V. A. Trapeznikov, addressed the plenary session with a report, "Automatics and Mankind."

In the report a characterization was given of the ever-growing role of automation and the most important scientific-technical problems facing scientists and engineers were stated: 1) the development of optimal control methods and synthesis of control structures approaching optimal; 2) the development of the principles of construction of self-adaptive and self-teaching systems; 3) the development of the principles of automatic machines for the planning of technical facilities; 4) the creation of reliably operating control apparatus.

It was emphasized in the report that an advance in quality can be obtained in automation, provided that the technological process, the basic technological equipment and the system of automatic control are worked out as a single combined complex.

More than 280 scientific reports were presented to the Congress, both on theoretical questions and on the solution of practical problems in the automatic control of various mechanisms and processes.

Sections organized for discussion of the reports were: the theory of continuous linear systems; the theory of continuous nonlinear systems; the theory of discrete systems; stochastic problems; the theory of self-adaptive systems; the theory of the structure and nature of signals; special mathematical problems; modeling and experimental methods of investigation; the electrical and magnetic elements of systems of regulation; electrical computing and modeling equipment; programming elements and machinery; counters, elements and systems of automatic monitoring and remote control of productive processes; pneumatic means of automation and computer technique; automatic monitoring instruments and equipment; the automation of machine construction; the automation of energetic systems; the automation of the chemical and petroleum-processing industry; the automation of electrical drives and electrical machinery; the automation of metallurgical processes; general questions (terminology, the training of specialists, etc.).

In the sections 139 reports on theoretical questions were heard; 330 men engaged in the discussions of the reports.

A group of five sections discussed problems of apparatus used in automatic control systems. Reports presented were devoted to discussion of new types of elements used in automatic control systems. Both electrical and magnetic elements of control systems and pneumatic means of automation were considered.

Fig. 1. In front of the Moscow State University building on the opening day of the Congress.

Two sections considered problems of counters and instruments being used in systems of automatic monitoring and control of productive processes. Reports by Soviet scholars were also heard in these sections, reports devoted to the utilization of radioactive isotopes and nuclear emissions for technological control: a report by V. A. Yanushkovskii and I. M. Toksar on "Apparatus for the technological monitoring of production using nuclear radiations," a report by V. G. Segalin, E. S. Spagovskii and A. B. Rudakovskii entitled "Some results of work on the utilization of radioactive emissions for the automatic control of mining and shaft sinking machinery."

In the first report there was emphasis on the need for standardization and unification of assemblies of apparatus for technological monitoring in which radioactive isotopes are used. Basic attention was given to relay methods of monitoring since in their utilization the standardization and unification of basic assemblies of apparatus can be carried out on a widespread basis. As an example of the use of the relay method there is cited the automatic monitoring of the delivery of intermediates to a multipositional automatic press, as well as contactless blocking in railroad transportation. The authors stated the basic mathematical dependences which permit calculation of the parameters of the electrical circuits of relay-action instruments. The report also discussed the possibilities of using and standardizing relay-action apparatus in modulated current registration of radioactive emissions and in continuous monitoring.

In the second report there was a discussion of problems connected with the development of apparatus which will permit, with the help of radioactive isotopes, monitoring the movement of machinery in the mining industry. The results of experimental work to determine the necessary requirements of the radiation source were stated.

Several reports were devoted to magnetic amplifiers, which are finding wide use, especially as a power amplifier section.

A large group of reports, totalling 81, was devoted to various systems of automatic control.

Reports on the automation of nuclear reactors were heard and discussed at the Congress.

A report by Picard (France) was devoted to digital systems of control of nuclear reactors: "Digital automatic equipment at an atomic energy installation." The report told the merits of such a scheme, pointed out the difficulties in creating it, including the selection of converters for the direct conversion of physical measurements (time, velocity, volume, pressure, temperature, etc.) into a series of coordinated electrical signals, the utilization of digital machines for a wide range of measurements, and the conversion rates attainable by the equipment, which limit the precision of the measurements. The author divided the values which must be controlled in a reactor into three groups according to the order of their technical difficulty: the data for monitoring, the data regarding danger to health and the data for control. In all it is proposed to conduct measurements at 1420 points.

Two models of equipment intended for monitoring were described in the report. The first of them (already built) is intended for monitoring damage to the cladding of heat-generating elements, and the second (being planned) for the centralized dosimetric monitoring of numerous points around the reactor. The equipment for the monitoring of the cladding of heat-generating elements is intended for a reactor with a graphite moderator and a gaseous heat-transfer agent. The essence of the method consists of exhaustion of the gas from the reactor through detectors according to a definite scheme. After analysis an electronic circuit decides whether the condition is normal or there are deviations from the norm.

Disturbances in the reactor are thus recorded and measured by an electronic machine, which informs a central panel of impending trouble. The machine has a memory device, in which are stored the data of the initial state in the reactor, and a comparator which determines whether the measured value has approached the boundary value. The electronic equipment is built completely of semiconductors. With the help of a special program the equipment is monitored every 24 minutes. The computer has a monitoring precision of ± 1%.

As a second example of the use of computer technique the report described centralized equipment for monitoring the intensity of radiation from the point of view of danger to the health of the attending personnel. The radiation is measured at 100 points. A functional scheme of a similar system was presented in the report.

The second report of the French delegation (author—Frank) was devoted to the automatic control of the "Minerva" reactor. In this experimental tank-type reactor rods are installed which provide control of the reactor by their rotation. The deflection angle is + 50°.

In the report of J. Veil' and T. Fridling (France) called "The automation of the control of nuclear reactors, optimal automatic control," the question of the use of optimizing computers for the control of reactors was also discussed. General ideas about the optimal control of nuclear reactors were expressed in the report. The authors think that the function of a computer should consist of memory of the preceding state of the reactor with all the operating constants, determination of the regime of further operation of the reactor according to the program and automatic selection of the best program from among the many alternatives.

Three cases were cited as examples:

1) compensation for xenon poisoning; in avoiding losss of time during elevation of the rods the machine can maintain the minimal negative coefficient of reactivity of the reactor, for which after shutdown an account of the degree of the xenon poisoning is given continuously;

2) prevention of destruction of the cladding of heat-generating elements; it is assumed that the machine can predict the further development of damage; to create such a machine sufficiently precise knowledge of the development of cladding breakdown is needed;

3) increase in the average yield of energy by heat-generating elements; it is proposed to use machines for the adjustment and tranfer of heat-generating assemblies.

The authors prefer digital computers.

Reports were also presented at the Congress on apparatus modelling the processes in nuclear reactors. In a report of N. Filipchik, V. Filipchik and T. Zelenskii (Poland) entitled "A method of mathematical modelling of physical processes without limitation of the region of change in parameter and its application to problems of the automatic control of nuclear reactors," a method of automatic change of scale in a continuously operating computer is discussed.

The method is based on automatic change of voltage on the consenser by switching an additional condenser in a given regime. The possibility of using this method to model acceleration of a reactor was examined.

In a report of G. Rekhberger and T. Zekvents (Austria) entitled "Modelling nuclear reactors by means of a digital model" a digital model of a nuclear reactor is described, which operates basically on the principle of discrete numeration. The authors think that a computer which operates on the principle of calculating machines is to be preferred over continuously operating machines as to the precision and the length of the operation. Schemes of such equipment based on this principle were presented in the report. Such a device is being made at the present time at the School of Advanced Technology (Vienna).

Fig. 2. In the conference room of the Congress.

In a report of Kachmarek (West Germany) entitled "A critical comparison of nuclear reactors with different systems of control" it was reported that investigations of the different schemes of automatic control devices of water-cooled and water-moderated reactors and organic reactors have been made on an electronic computer.

The proceedings of the Congress will be published in Russian and English in 1961.

THE SECOND CONFERENCE ON MAGNETIC HYDRODYNAMICS

The Second Conference on Theoretical and Applied Magnetic Hydrodynamics, organized by the Institute of Physics of the Latvian SSR Academy of Sciences, was held in Riga from June 27 to July 2,1960.

Four sections functioned at the conference: 1) theoretical questions of magnetic hydrodynamics; 2) applied magnetic hydrodynamics; 3) theoretical questions of plasma physics; 4) experimental questions of plasma physics.

Seven survey reports were heard at the plenary session, among them a report by D. A. Frank-Kamenetskii entitled "Plasma – The fourth state of matter" and a report by V. D. Shafranov entitled "The stability of plasma" (read by B. B. Kadomtsev).

Thirty-one reports were presented in the section on theoretical questions of plasma physics.

A report of V. I. Kogan, Institute of Atomic Energy of the USSR Academy of Sciences (IAE AS USSR), was devoted to the influence of fluctuating microfields on multiple collisions in a gas of charged (or gravitating) particles. On the example of several typical problems in the theory of multiple collisions it was shown that the joint action of many field particles on the test particle does not change the fundamental "binary" character of the collisions; but not only the size of the system and the Debye screening radius, but also the longitudinal pass of the test particle can play a role in the maximal length of the section in the Coulomb logarithm.

In a report of A. M. Morozov and L. S. Solov'ev (IAE AS USSR) the results of calculations of the different variations in the transitional layer between plasma and a magnetic field disregarding collisions were presented.

S. V. Iordanskii (V. A. Steklov Mathematical Institute, Academy of Sciences, USSR) discussed the excitation of electronic unidimensional oscillations in plasma during passage of an electronic beam between two electrodes having an assigned potential which is negative relative to the plasma. Formulas obtained for the case of low intensity of the beam and great distance between the electrodes show that the dependence of the oscillation frequency with a very large increment on the plasma frequency has a stepwise character, wherein the maximal increment is obtained when the oscillation frequency is equal to the plasma frequency. These results are in qualitative agreement with the experiments of Looney and Brown, made during great intensities of the beam.

A report by D. A. Frank-Kamenetskii (IAE AS USSR) on the natural oscillations of organic plasma aroused interest. It was explained that organic plasma has natural frequencies corresponding to magnetophonic resonances (resonance swings). The conclusion of the report is that these resonance frequencies can be used for the ionization and high-frequency heating of plasma.

L. I. Rudakov (IAE AS USSR) discussed collisionless damping and swings of waves distributed across a magnetic field in a unidimensional plasma.

The damping (swinging) of the waves is caused by particles whose drift velocity in a nonhomogeneous field is near the phase velocity of a wave or particles for which the oscillation frequency of the field in the system of coordinates associated with the drifting particles is near the cyclotronic frequency.

A report of M. V. Konyukov (Tul'sk State Pedagogical Institute) was devoted to nonlinear Langmuir oscillations of ions in plasma; it discussed nonlinear oscillation of a unidimensional plasma in quasihydrodynamic approximation.

In a report of L. S. Bogdankevich, B. M. Bolotovskii and A. A. Rukhadze (Institute of Physics, Academy of Sciences, USSR) (FIA) the transition of emission of a charge on the front of a strong shock wave was explained. It is confirmed that the energy losses of charge particles for transitional emission are comparable to the ionization losses at energies of $\sim (10^5\text{-}10^7)mc^2$.

A report of B. B. Kadomtsev and A. V. Nedospasov (IAE AS USSR) on the instability of a positive column in a magnetic field and anomalous diffusion was of great interest to a large number of those participating in the conference. The report included an explanation of the experiment of Lenert and Khu, who found a sharp change in the character of the dependence of the electrical field along the column of discharge from an external magnetic field at a certain critical field N_{cr} of the order of several kilogauss.

About 25 reports were heard in the section on experimental questions of plasma physics.

I. M. Podgornyi and V. N. Sumarokov (IAE AS USSR) discussed the results of work on the injection of clots of plasma (accelerated by an electrodynamic method) into a magnetic field formed by two coils switched on toward one another. It was shown that the life of the plasma in such a system is several tens of microseconds.

A report of L. V. Dubovoi, O. M. Shvets and A. G. Ponomarenko (Institute of Physiotherapy, Academy of Sciences, USSR) was devoted to the conductivity of plasma in strong electrical fields. In plasma with a density of 10^9-10^{10} particles per cc at a hydrogen pressure of $3\cdot 10^{-2}$ mm Hg in a magnetic field H = 2-3 ke a high-frequency electric field of 0.1-100 ev was created directed in parallel with or perpendicularly to H. The degree of absorption and widening of the spectrum of the light wave frequency signal (3 cm) was determined, which is proportional to the frequency of the collisions of electrons with atoms. The authors adduce dependences of frequency of the collisions on the electrical field. They found the presence of an additional mechanism of dissipation of the energy of the particles which cannot be explained by pair collisons. In the region of change in the electrical field, where a substantial deviation of the collision frequency is observed in comparison with pair collisons, there arise intensive noises. A similar result is obtained for ionic cyclotronic oscillations.

A. V. Orlinskii (IAE AS USSR) reported on investigation of the shock wave in a conic discharge tube. An explanation was given for dependence of the velocity of the front of the shock wave formed in a conic discharge chamber and distributed along the axis of the glass cylinder on the angle at the apex of the cone α, the initial pressure of the gas and the voltage on the condenser battery. The maximal velocity of $\sim 2\cdot 10^7$ cm/sec was attained at $\alpha/2 = 12°$.

A report of I. F. Kharchenko, Ya. B. Fainberg and others (FTI AS USSR) discussed the interaction of a modulate electronic beam (modulation frequency, ~5000 Mc) with plasma in a magnetic field. They found a dependence of the energy loss by the beam on the magnetic field. They discovered regions of instability of the beam (the increased loss of energy by the beam is $\left.\frac{dE}{dx}\right|_{max} \sim \frac{1E}{3}$) at certain values of the magnetic field. If the beam is not modulated these regions are broadened. The authors think that in the given case an instability of an electrostatic type occurs.

V. G. Safronov, R. V. Mitin and others (FTI AS USSR) have investigated high-frequency oscillations of the plasma pinch of a Lewis angular vacuum arc. The arc is ignited at a pressure $p \sim 10^{-6}$ mm at a current of 150 -300 a in a magnetic field H = 100-5000 gauss. The temperature and ion concentration are determined optically. It follows from the measurements that the temperature of the ions is $T_i \sim 4\cdot 10^4$ °K and the plasma is completely ionized. Oscillations were studied in the region of frequencies from 100 kc to 3800 Mc. Strong oscillations with frequencies of 1-2 Mc were found. The frequency of the oscillations depends linearly on the magnetic field. The distribution of high-frequency fields of these oscillations has been studied. The conclusion is drawn that these oscillations represent magnetohydrodynamic waves.

During the convention those who participated in it became acquainted with the work being done in the Institute of Physics of the Latvian Academy of Sciences.

V. Pistunovich

THE FIRST CONFERENCE ON NUCLEAR METEOROLOGY

At the end of June and beginning of July 1960 a conference was held in Vil'nyus on problems on actinometry, atmospheric optics and nuclear meteorology. The conference had been convened by the Institute of Geology and Geography of the Academy of Sciences of the Lithuanian SSR jointly with the Subcommission on Radiation of the Commission on Physics of the Atmosphere of the USSR Academy of Sciences, the Board of the USSR Hydrometeorological Service and establishments of the USSR Ministry of Higher Education. Several representatives of scientific establishments of the Lithuanian SSR, of Leningrad, Moscow, the Kazakh SSR and other cities and republics participated in the work of the section on nuclear meteorology.

A survey report on "The basic problems of nuclear meteorology" was read by B. I. Styro. Greatly expanding investigations of radioactive phenomena in the atmosphere make it possible to classify in a separate and independent discipline, "Nuclear Meteorology," all the questions connected with these phenomena. First of all it is necessary to study the material composition of the radioactivity of the atmosphere, which is composed of radioactive substances that get into the earth's atmosphere by the action of cosmic radiations and substances which get into the atmosphere as a result of human activity. The atmosphere can be considered as a unique region of transformation of matter. In the report many shortcomings were pointed out in the method of investigating the radioactivity of atmospheric objects (air, precipitation, droplets and snowflakes, cloud elements, etc.), and mention was made of the need for investigations of the spacial distribution in the temporary fluctuations of atmospheric radioactivity, as well as its connections with changes in the meteorological elements and the weather. Analysis of the processes of contamination and self-purification of the atmosphere from radioactive impurities has shown that cloud systems play a basic role in this purification. Finally, the report discussed meteorological problems which can be solved by study of atmospheric radioactivity.

The reports of V. Yu. Potsyus and L. V. Kirichenko were devoted to a study of the natural radioactivity of the lower half of the troposphere. Kirichenko told of investigations carried out in the Institute of Applied Geophysics on the aerosol constituents of the natural radioactivity of the air up to a height of 6 km. The investigations were made with the help of flying laboratories by filtering the air through porous filters. A complex inversional distribution of radioactive aerosols according to height was noted; on days with a stable stratification the distribution was exponential, and this made it possible to obtain numerical data on the transfer coefficient.

Potsyus told of measurements of radioactivity at local points in a cloud by the use of original devices for collecting specimens of cloud fluid and the measurement of radioactivity by the radiographic method. The material composition of the radioactivity of cloud elements does not differ from the composition of radioactivity of the earth's crust. The distribution of the amount of radioactive substances in a cloud is characterized by a maximum in the center, and in thick cumuli even by a second maximum of the basic one. The amount of radioactivity corresponds well with the aqueousness of the cloud. Accumulation of radioactive substances (coefficient of accumulation, 1000) occurs in a cumulus.

In a report of T. N. Nedvetskaite and B. I. Styro on the 24-hour course of α-emitting radioactivity they presented the results of a study of the 24-hour course of radioactive substances in the air by the radiographic method. For intramass weather conditions a correlation was established between the concentrations of radioactivity, on the one hand, and the absolute humidity of the sublayer near the earth, on the other. Under frontal weather conditions these connections are undecipherable. The approach of a front usually is associated with a decline in natural radioactivity of the air at the surface of the earth.

Two reports were devoted to the method of measuring atmospheric radioactivity. V. P. Matulyavichus reported on a multichannel recorder of the level of atmospheric radioactivity, designed in the Institute of Geology and Geography of the Academy of Sciences of the Lithuanian SSR. Features in the design of the recorder enable simultaneous recordings to be made of a number of characteristics of radioactivity and to separate the long-lived and short-lived components.

In a report of V. P. Shvedov, Z. T. Gritchenko, G. V. Yakovlev and M. I. Zhilkin they discussed a method of collecting specimens of air by filtration of the air through simple filters and collecting samples of the sediments on ethylene films. By means of end-window counters and γ-spectrometers measurements were made on both the total activity and the activity with respect to individual radioisotopes.

A number of reports were devoted to study of the problem of self-purification of the atmosphere from radioactive contaminants. D. D. Solodikhina told of the results of measurements of the radioactivity of atmospheric precipitates taken at different heights on mountains, on the continent and over the ocean. An attempt is being made, on the basis of the data presented, to estimate the coefficient of the washing-out of precipitates of radioactive substances from the air.

Ch. A. Garbalyauskas showed that, according to the results of measurements of the radioactivity of settling dust and atmospheric precipitates, it can be confirmed that up to 80% of all the settling radioactivity of artificial origin is washed out by the latter. He introduced the concept, "factor of self-purification of the atmosphere," presented as the ratio of the separate radioactivity of atmospheric precipitates and dry dust to the amount of radioactive dust.

In a report of V. P. Shvedov, L. I. Gedeonov, Z. T. Gritchenko and G. V. Yakovleva it was shown that the quantity of radioactivity washed out by precipitations can be presented in the form of three terms: 1) the portion of the radioactivity held by drops in a cloud; 2) the portion of the radioactivity held during precipitation, and 3) a negative term, reducing the activity of falling precipitate on account of dilution of the radioactive substance in water. An attempt is being made to establish a regularity in the accumulation of radioactivity in the earth's air after its purification by rain by means of the diffusion of radioactive substances from the upper layers of the atmosphere.

S. G. Malakhov told of the amounts of fission products deposited on the earth as a result of nuclear weapons testing, presented calculated data on the Sr^{90} concentration and pointed out the sharp maximum in the concentration of long-lived β-active aerosols observed in the spring.

In a report of V. P. Shvedov, Z. T. Gritchenko and M. I. Zhilkina they presented the actual data of a radiochemical analysis of samples of air in the atmospheric layer near the earth for Sr^{89}, Sr^{90}, Y^{91}, Ce^{141} and Cs^{137}. It was established that the period of transition of long-lived isotopes of Sr and Cs from the stratosphere into the troposphere is shorter than was previously supposed. Moreover, it was noted that during the fall of precipitates more Cs^{137} is held than Sr^{90}.

In a communication of B. I. Styro, Ch. A. Garbalyauskas, T. N. Nedvetskaite, I. S. Tomkus and K. K. Shopaiskas on atmospheric radioactivity with a long half-life they reported the results of radiographic measurements of α-radioactivity of the air in the course of several months of 1958-1959. In this the uranium and thorium components of radioactivity were separated. Certain features of the peak and background radioactivity were pointed out and an attempt was made to link up the background radioactivity with the types of air masses, atmospheric fronts and types of weather.

A survey report by I. L. Karol' and S. G. Malakhov was devoted to a discussion of the geographic distribution of fission products and a critical review of the hypotheses of Libby, Stewart, Makht and Mortell on the global distribution of the products of nuclear arms tests in the atmosphere.

G. A. Sereda, O. S. Berlyand, V. P. Shvedov, V. A. Lavrenchik and others spoke in the debates. On the basis of the work of the section it was decided to adopt a resolution in which the need for expansion of research in the area of nuclear meteorology was emphasized.

The materials of the conference will be published in 1961 in "Nauchnye Soobshchenie" ("Scientific Communications") (Vol. XIV, No. 3), published by the Institute of Geology and Geography of the Academy of Sciences of the Lithuanian SSR.

B. I. Styro

THE SYMPOSIUM ON DOSIMETRY

A symposium on certain problems of radiation dosimetry was held in Vienna on 7-11 June 1960.

Participating in the work of the symposium were 183 representatives of 23 governments and international organizations. The delegation of the USSR was represented by K. K. Aglintsev, V. V. Matveev, V. A. Schastnoi and the author of this article. About 70 reports were heard at the symposium, on various problems of dosimetry (instruments and methods of dosimetry of services in safety technique, scintillational, photographic, chemical, thermoluminescent and calorimetric methods of dosimetry, methods of dosimetry of mixed γ-neutron fields and certain theoretical questions of dosimetry).

A large survey report on fundamental dosimetric problems in connection with the monitoring of defense from ionizing radiation was presented by K. Morgan (USA). In spite of the fact that the report did not contain any data which were new in principle it was of great interest. An analysis was given in the report of the evolution of ideas about the maximum permissible level of exposure to radiation, the general path of the development of monitor-dosimetric apparatus and of instruments for dosimetric control now existing in the United States.

It should be noted that there is a very wide assortment of apparatus used for purposes of personnel monitoring. Along with condensators, ionization chambers and film badges there is use of dosimetric glass and also of chemical methods of dosimetry. A rather extensive collection of dosimetric instruments serves for the measurement of the contamination of workers' hands, bodies and clothing.

The photographic method of individual monitoring continues to be used intensively in dosimetric practice. It has received the furthest development both along the line of use of a set of films with various sensitivities in order to expand the range of measurable doses and along the line of use of a set of different filters and foils for measurement of γ-and β-rays, thermal and fast neutrons. In particular, in West Germany, Italy, Brazil, Yugoslavia, Finland and Switzerland they are adopting a method of photographic monitoring (report by Vaksman, West Germany) based on the use of two kinds of film with sharply different sensitivities (1:500). The "four-film" photomethod was also presented in a report of V. Khuttsinger and D. Poretti (Switzerland). The plate is divided into four fields covered by the following filters: 0.1 mm plexiglas, lead - tin and lead - cadmium. The first field gives the $\beta + \gamma$ dose, the second $\frac{1}{2}\beta + \gamma$, the third and the fourth γ + thermal neutrons. Differences in blackening enable one to determine the dose from the different forms of radiation.

Much attention was given at the symposium to the development of a method of threshold detectors for the determination of tissue doses of neutrons. This method is widely used for the dosimetry of streams both within the reactors and beyond its shielding (reports of D. Braun and R. Milson, Sweden; D. Moteff and Biver, USA; F. Davis, USA). The reports presented the relationships between the measurable activities of foils and tissue doses on account of change in the spectrum of the fission neutrons as a result of their passage through different layers of shielding and multiple dispersion in the human body. A similar dosimeter is used for determining the absorbed dose in accident cases. The range of measurement here is very large (5-1000 RBE).

For dosimetry of fast neutron streams to monitor the shielding there is wide use of proportional counters with a polyethylene cathode, filled with a mixture of argon, methane and carbon dioxide gas (report of I. Anderson, Sweden; D. Dennis and N. Lusmore, Great Britain). The apparatus reliably permits registration of the level of streams of neutrons lying below the maximum permissible (for example, at a dose of 0.1 RBE per week the number of counts amounts to 80 imp/sec.)

Seven reports were devoted to the scintillation method of dosimetry. In two of the reports (M. Forte and A. Konst, Italy; L. Grache and I. Koekhlin, France) results were presented of investigation of a method of discrimination of impulses arising in scintillators from different particles. It was shown that the impulses of protons and α-particles can be separated in cesium iodide crystals. In liquid organic scintillators of large capacity (up to 9 liters) separation of γ-rays and neutrons is possible; the authors think that this method will permit making photographs of the spectra of neutrons with a resolution of ~ 30%.

The report of S. Baldin and V. Matveev (USSR) was devoted to a description of an arrangement for an investigation of scintillation gas counters. With use of xenon and a model FÉU-24 photomultiplier the energetic resolution for α-particles of Po^{210} reached 5%.

Also reported were the results of investigations of certain materials used in scintillation counters as light converters, reflectors and optical adhesive. (S. Baldin, V. Matveev and A. Sokolov, USSR).

Seven reports dealt with chemical methods of dosimetry. The development of chemical methods of dosimetry is proceeding along the line of increased sensitivity of the methods and accuracy of the measurements. The latter is linked with determining the yield of chemical reactions occuring under the influence of ionizing radiation.

In a report of G. Tilens (Belgium) it was shown that the use of a ferrosulfate dosimeter in the range of 300 r and higher is possible in the accurate determination, with a spectrophotometer, of the quantity of trivalent iron ions formed.

The use of benzoic acid as a stabilizer leads to increase in the reaction yield from 15.5 to 66 ions of trivalent iron per 100 ev of absorbed energy. This enables one to reduce the lower limit of the measurements to 50 r. It was also shown that the sensitivity of the ferrosulfate method can be raised in measuring the coloration of a solution in the presence of orthophenanthroline (report of Buzige and others, France).

Determination of the reaction yield for a ferrosulfate dosimeter has been made for a wide energy range. For Co^{60} radiation (report of N. Holm and others, Denmark) the reaction yield value is 15.68 ± 0.07 ion pairs per

100 ev of absorbed energy. The reaction yield increases somewhat upon increase of the photon energy to 30 Mev (report of V. Minder, Switzerland).

Four reports dealt with measurement of the ionizing radiation dose by analysis of the darkening of optical glass. Phosphate glass activated with silver is used to measure γ-rays and thermal neutrons. It was shown in a report of S. Kondo (Japan) that the yield of fluorescence is proportional to the absorbed dose of γ-rays and thermal neutrons. The author used this method to measure doses of γ-rays and neutrons in the thermal column of a reactor. The range of the measurable doses was 50-10^4 rad. New phosphate glasses containing lithium and boron have been developed for measuring thermal neutrons. In a report of P. Ikoto and Kh. Sapat (Japan) two types of such glass are described: Li = 1 and LiB = 1. In Li = 1 glass there are $LiPO_3$ (46.3 wt. %), $Al(PO_3)_3$ (46.3 wt. %) and $AgPO_3$ (7.4 wt. %). In LiB = 1 glass there are $LiPO_3$ (45 wt. %), $Al(PO_3)_3$ (45 wt. %), $AlPO_3$ (7.3 wt. %) and B_2O_3 (2.7 wt. %). The sensitivity of the glasses with regard to γ-rays is three times greater than that of Shul'man glass (composition: KPO_3 – 23.15 wt. %, $Ba(PO_3)_2$ – 23.15 wt. %, $Al(PO_3)_3$ – 46.3 wt % and $AgPO_3$ – 7.4 wt. %), and for thermal neutrons more than 10 times for Li = 1 glass and 13 for LiB = 1 glass. By means of LiB = 1 glass it is easy to measure thermal neutron doses of $5 \cdot 10^6$ neutrons/cm^2.

Two reports dealt with thermoluminescent methods of dosimetry. The investigation of thermoluminescence (the liberation of the stored energy of ionizing radiation during heating of luminophor) is a comparatively little developed dosimetric method. In the work of D. Shul'man and others (USA) and M. Schon (West Germany) calcium fluoride served as the luminophor, activated by manganese. Excellent preservation of the light sum is explained by the presence of a large number of deep electron traps. The dosimeters have excellent linear characteristics and are used in the interval from several milliroentgen units to 10^4 r. The losses of stored energy amount to 10% after the first 16 hours and then 1% per day. To measure thermal neutrons the luminophor used is lithium fluoride (the measurement of very small streams, starting at $5 \cdot 10^3$ neutrons/cm^2, is possible).

The dosimetry of mixed γ-neutron fields attracted much attention at the symposium. To this section one should refer reports on threshold neutron indicators, on the use of proportional counters for fast neutron dosimetry, on calorimetric methods and ionization chamber methods. To determine energy absorption in various substances mixed in the reactor channel, various methods are used. The use of adiabatic calorimeters made of various substances aroused much interest.

In a report of A. Anderson and D. Dinaker (Great Britain) a detailed analysis was given of the method of adiabatic calorimeters (a cylinder with a diameter of 1.27 and height of 2.54 cm) made of beryllium, graphite, aluminum, sulfur, iron, lead, bismuth, polystyrene, polyethylene, beryllium oxide and silicon. A copper-constantan thermocouple was used to measure temperature. By comparing the energy absorbed in the body of the calorimeter made of the different materials one can calculate the absorbed dose from fast neutrons and γ-rays and for other substances.

Two reports were devoted to the development of methods of dosimetry for mixed streams by means of ionization chambers. In a report of Zh. Neiri and F. Williamson (Great Britain) they discussed a method proposed by them to determine tissue doses of neutrons and γ-rays with a magnesium chamber filled with argon and chambers whose walls and filling gas contain hydrogen (the walls of the chamber contain a mixture of graphite, polyethylene and polystyrene; acetylene is continuously supplied as the gas filling the chamber). This chamber has been compared with the Failla-Rossi tissue-equivalent chamber used in the USA. A comparison has been made for various manoenergetic streams of neutrons, from 430 kev to 1.8 Mev, and for neutron streams which have a continuous spectrum with an average energy of 3 Mev. The authors obtained satisfactory coincidence in determining the values of the tissue dose. The maximal divergence did not exceed 23%.

In the work of Yu. Bregadze, B. Isaev and V.Kvasov (USSR) use was made of three homogeneous chambers with different hydrogen content in the walls and with corresponding gaseous filling. It was shown that similar chambers are suitable in a broad range of neutron and γ-ray energies. Even in the presence of a high γ-background one can determine the tissue dose with an accuracy completely adequate for the purposes of radiobiological and radiation-chemical experiments.

Two reports dealt with the investigation of Herst counters for the determination of tissue doses of fast neutrons and γ-rays. In the first report, by D. Herst, USA, and E. Wagner, West Germany, they investigated the possibility of separate determination of the neutronic and γ-dose with a Herst counter and with an ordinary halogen counter, whose course was strictly adjusted with the help of a lead filter. The possibility was shown of determining a tissue dose of neutrons of ~ 0.001 rad/hr on a background of γ-rays of 100 rad/hr. In the second report (by F. Pott and E . Wagner, West Germany) separate determination of the neutron and γ-dose was made on one and the same Herst counter, but operating in the one case in a regime of proportional amplification with corresponding discrimination of the γ-background, and in the other case, in a regime of an ionization chamber, when there is change in the total ionization current caused by the recoil protons and γ-rays. Knowing the value of the gas amplification coefficient one determines with simple correlations the dose absorbed from the fast neutrons and γ-rays.

Six of the reports dealt with the theoretical principles of dosimetry. The reports reviewed the operating mechanism of ionization chambers, the experimental and theoretical principles of the metrology of ionizing radiations and certain questions in connection with the interaction of radiations with substances.

In a report of K. Aglintsev, V. Mitrofanov and V. Smirnov (USSR) they interpreted the processes taking place in ionization chambers for measurement of γ-ray doses on the basis of investigations of the energetic spectra and the angular distribution of secondary electrons knocked out of the chamber walls by γ-rays and penetrating the measuring area. The absolute yields of secondary electrons and the experimental values of the equilibrium thickness of the chamber walls were determined for Co^{60} and Cs^{137} γ-rays.

In other reports a calibrating device for the reproduction and transfer of Roentgen units in the range of 250 -3000 kev (K. Aglintsev, USSR) was described, and recombination losses in ionization chambers in a high intensity field were reviewed (R. Levinger, USA). Interest was aroused by new data of D. Neifeld (USA) on the stopping power of heavy particles, determined on the basis of experimental data for the stopping power of protons in the energy range of 20-250 kev. The results obtained with regard to linear transfer of energy give higher values for heavy particles than those accepted previously.

It is proposed to publish the material of the symposium in a separate collection.

V. M. Isaev

APPLICATIONS OF IONIZING RADIATIONS
FOR INCREASING AGRICULTURAL CROP YIELDS

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The effect of x-rays, and consequently of other forms of ionizing radiations on the growth and development of plants was discovered almost simultaneously with the discovery of the rays themselves.

It was found that high irradiation doses destroy the plants. When the doses are reduced somewhat, ionizing radiations cause profound genetic alterations, including monstrosities alongside of valuable and useful mutations, when a fraction of the irradiated plants manages to survive. Selective sampling of the progeny of such mutants makes possible a singling out of new and economically valuable strains of agricultural crop plants. Many new and valuable strains of different agricultural crops have been produced by this method, including, for example, a rust-resistant oat strain, an erect barley plant, a more highly productive strain of white mustard.

Weak radiation doses stimulate the growth and development of plants, accelerate their ripening, and in many cases improve the quality of the raw material resulting from processing of the plants.

Lethal doses, mutagenic doses, and stimulating doses are specific for different species, and sometimes even for different strains of plants. In studying the effect of weak radiation doses on plants, it was found that the stimulating action is due not only to the total dosage, but is also affected by the irradiation conditions, the conditions in the ambient medium, the physiological state of the irradiated seeds. For example, the irradiation effect increases sharply in response to increased moisture in the irradiated seeds, and slackens off in response to a drop in the temperature of the surrounding air and in response to oxygen deficiency. The sensitivity of the seed response to irradiation increases as a factor of seed storage period length: old seeds are more radiation-sensitive than seeds from the previous year's crop. Irradiation effects also vary depending on the interval elapsed between irradiation and sowing of the seeds. When seeds are sown immediately or moistened following exposure, the effect exerted by ionizing radiations suffers pronounced attenuation. Failure to take due account of a complex of conditions such as those enumerated here, and sometimes complete ignorance of those conditions led for a long time to the recording of contradictory findings relating to exposures of seeds to low-level radiation doses, which placed a cloud over the effectiveness of the stimulating effect of ionizing radiations [1, 2].

However, experimental materials accumulated by Soviet and foreign research workers during recent years [3-5] have eliminated any vestige of doubt surrounding this question.

At the Institute of Biophysics of the USSR Academy of Sciences, a large and imposing number of laboratory and field experiments have been conducted on determinations of the radiation doses capable of stimulating the growth and development of agricultural plants. As a result of these investigations, it was found that gamma rays stimulate growth and development of radishes at a dose of 1000 r, carrots at 2500 r, cabbage at 2000 r, tomatoes at 1000 r, cucumbers at 300 r, peas at 300 r, corn at 500 r. Data of field experiments conducted on radishes, carrots, cucumbers, and cabbage were verified under semi-production conditions and production conditions. A 19--30% increase in the radish crop was registered over a three-year period; the greatest increment took place during the earliest stage of sowing. In addition, irradiation of seeds prior to sowing accelerated the ripening of root vegetables by 5 to 6 days. Verification of these field experiments under farm production conditions took place at the Zarech'e No. 2 vegetable combine of the Moscow district; a crop yield increment of 11% for radishes was obtained in a 1.5 hectare plot, amounting to roughly a ton of additional produce from a single hectare.

Irradiation of carrot plants prior to sowing increased the yield of the vegetables by an average of 22%, according to data on field experiments stretching over a three-year period. During 1957, production sowing of irradiated carrot seeds was carried out at the Krasnodar vitamin combine on a 5 hectare plot; the vegetable crop was increased by 24% higher than the crop obtained from unirradiated seeds. The production sowing of irradiated carrot seeds was repeated on a larger area during 1957 (this time on a plot of 26.5 hectares). Despite extremely unfavorable weather conditions prevailing that year, resulting from a severe and prolonged drought, the yield of irradiated carrots was 30% higher than the yield of unirradiated carrots.

In all experiments and production programs, it was noted that the increase in carotene content fluctuated between 3 and 12% in seeds irradiated prior to sowing.

Three-year observation programs have provided ample evidence backing up the findings of pre-sowing irradiation experiments on dry seeds, resulting in the introduction of this practice into regular use with the aim of increasing the crop yield of many agricultural crop species.

N. M. Beregina

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USSR. The nuclear reactor at the Nuclear Physics Institute of the Uzbek SSR Academy of Sciences has demonstrated high quality of performance, reliability, and faultless operation in a year's service. The team of young research workers servicing the reactors has undergone a special training course. This has made possible the organization of an excellently trained staff of reactor personnel, including many representatives of the local nationality. The use of the reactor is contributing its part to raising the level of scientific research work in Uzbekistan.

Applications of radioactive isotopes are also on the increase in the Republic. Many branches of industry have been successfully automated by putting radioactive isotope instruments to work.

USSR. During April and May 1960, the annual scientific conference of the Moscow Engineering and Physics Institute met in session. Approximately 150 reports were heard at the sixteen sessions held, for the most part reflecting work done at the Moscow Institute. Reports of research work pursued at other institutions were also heard. Over 500 representatives of the Institute and other organizations in Moscow, Leningrad, Dubna, Khar'kov, and other cities took part in the discussions. As in previous years, the discussions had the effect of expanding the scope and significance of the Conference and advanced it beyond the range of an intra-institutional gathering. The most interesting reports and papers are being published in the periodical literature and in symposia published by the Institute in Moscow.

Gabon. The uranium occurrence at Mounan near Franceville, whose reserves are estimated at 20 million tons of ore (4-5 thousand tons of pure uranium), will be exploited in open-pit fashion, first to a depth of 80 meters, then to a second tier 200 meters down. Underground-level mining is expected to follow depletion of the open-pit ore.

Ghana. For two districts covering 16,000 km^2, comprehensive aerial gamma surveys and aeromagnetic surveys have been proposed. These regions include most of the gold-bearing and manganese occurrences of the nation, plus promising mineralized zones.

Poland. Installation of an isotopes laboratory is being planned at the Institute of Biology and Plant Physiology at Radzikow. A cobalt source will be used to irradiate plants.

Yugoslavia. The country's third reasearch reactor is in the planning stage. The reactor will be built at the Ljubljana Research Institute. The reactor power rating will be slightly lower than those of Yugoslavia's other two research reactors.

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pp. 435-442, November, 1960

G. Ya. Sergeev, V. V. Titova, K. A. Borisov. Metallovedenie urana i nekotorykh reaktornykh materialov [Metals technology: Uranium and Various Reactor Materials]. Moscow, Atomizdat, 1960, 362 pages, 11 rubles.

This book gives an account of the metals science of uranium and uranium alloys, as well as several structural materials of nuclear interest. The latter category involves those problems related to the specific influence of reactor core conditions on the materials. The book contains 14 chapters, Chapter I describes the performance conditions of nuclear fuel and structural materials in reactors. Chapters II-IX are devoted to uranium: uranium metallography, mechanical properties, plastic deformation, texture, the effect of irradiation on the dimensional stability and physical-mechanical properties of uranium, the effect of thermal cycling on the dimensional and structural stability of uranium, and heat treatment and heat treatment plus machining of uranium. Chapter X describes uranium alloys. Chapters XI-XIV are devoted to reactor structural materials, and also to the elements of production technology using integral metal components.

The book is written for scientific workers and engineers engaged in the field of reactor design. It may also be used as a textbook by students in the appropriate disciplines.

V. K. Markov, A. V. Vinogradov, S. V. Elipson, A. E. Klygin, I. V. Moiseev. Uran, metody ego opredeleniya [Uranium and Techniques of Uranium Determination]. Moscow, Atomizdat, 1960, 263 pages, 9 rubles, 60 kopeks.

This book describes the chemical and physicochemical properties of uranium and several uranium compounds. The theoretical foundations of the techniques of separation of uranium from other elements are discussed, as well as methods of qualitative and quantitative uranium determination. Gravimetric, volumetric, photometric, electrometric, fluorometric, and radiometric techniques for determining uranium are treated in detail. A list of the pertinent literature appears at the end of each chapter.

The book may prove useful as a textbook in chemical and metallurgical advanced technical schools and trade schools, and also as a practical manual for workers in in-plant laboratories and research institutions.

G. I. Petrov, M. V. Kutenkov, I. M. Tenenbaum, L. S. Evseeva, Metody geologo-geofizicheskogo obsluzhivaniya uranovykh rudnikov [Methods of geological and geophysical operations in uranium mines]. Moscow, Atomizdat, 1960, 218 pages, 8 rubles, 80 kopeks.

Basic information on morphological modes of uranium occurrences, the radiological properties of uraniferous ores, industrial specifications for uranium ores are presented in concise form. Systems of exploration and development of uranium ore bodies are described. Methods of geological surveying of occurrences, paper work in geological and geophysical operations, ore assay, drillhole logging, and technological sampling and assay methods, etc., are discussed. The last two chapters deal with the problems of expediting the flow of stocks and planning of ore production, and hydrogeological operations in mines. A list of the pertinent literature is appended.

The book is intended primarily for the use of specialists beginning their work in uranium mining installations. It may also prove useful to workers of mining and mill assay shops engaged in determining the quality of mined uranium ore and enrichment products.

N. G. Serebryakov, M. A. Gracheva. Radioaktivnye izotopy zolota Au^{198} i Au^{199} [The radioactive gold isotopes Au^{198} and Au^{199}]. Moscow, Atomizdat, 1960, 20 pages, 45 kopeks.

This brochure acquaints the reader with the methods used in fabricating the radiogold isotopes Au^{198} and Au^{199}, and preparations and sources containing those isotopes; it cites their physicochemical characteristics and indicates the field of applications. Emphasis is placed on the particularly widespread use of radiocolloids of gold in medicine for the treatment of malignant neoplasms. The brochure is written for a broad readership interested in problems of medical radiology and labeled-atom techniques applied to scientific research.

V. A. Sokolov, I. K. Kulagina. Radioaktivnyi izotop kal'tsiya Ca^{45} [The radioactive calcium isotope Ca^{45}]. Moscow, Atomizdat, 1960, 20 pages, 50 kopeks.

The brochure describes the radioactive properties of isotopes in general, methods for producing Ca^{45}, and presents the basic information on the synthesis of Ca^{45}-tagged compounds. Examples are cited of applications of Ca^{45} for scientific and other purposes, and basic information is given on safety techniques in handling radioactive materials.

The brochure is aimed at readers with at least elementary acquaintance of the field of radiochemistry, and interested in problems involving applications of radioactive isotopes.

R. Jung. Yarche tysyachi solnts. [Translation from the English of Brighter Than a Thousand Suns.] Moscow, Atomizdat, 1960, 336 pages, 8 rubles, 90 kopeks.

The book describes the basic stages in the development of modern nuclear physics, the birth of the concept of nuclear weaponry, and the gradual fruition of this concept into reality. The author tells of people participating in the creation of nuclear weapons, of the circumstances in which they worked, of political and other factors affecting their work. The author describes the maturing of the Manhattan project, the first atomic explosion at Alamagordo, the atomic explosions over Japan. He recalls the terror caused by rumors circulating about a German uranium bomb during the second world war, the sensational chase after the alleged inventors of this bomb (the "Alsace mission"), the events related to the development of the hydrogen bomb, etc.

The book will be of interest to a wide audience.

N. I. Shteinbok. Primenenie radioaktivnykh izluchenii v izmeritel'noi tekhnike [Applications for radioactive radiations in measurements work]. Moscow-Leningrad, Mashgiz, 1960, 288 pages, 10 rubles, 60 kopeks.

The book presents the outstanding physical phenomena which underlie the basis of the utilization of radioactive radiations. Problems of the ionization of gases, the laws governing radioactive disintegration, and the properties of radiations are discussed.

The information required for a judicious choice of radioactive isotopes and nuclear radiation sources fitted to a given application is presented. Techniques of measurements based on the use of radioactive radiations are described, and examples are cited of the use of radiations in a variety of measuring instruments.

The book is written for engineering and technical workers and research workers engaged in the field of measurements work and automation. It may also be useful for students in the corresponding disciplines in advanced technical training schools.

K. Schmidt. Nutzenergie aus Atomkernen [in German: Useful energy from atomic nuclei]. Berlin, Walter de Gruyter, Volume One, 1959. Volume Two, 1960. 1337 pages.

The first volume presents a brief exposition of the fundamentals of nuclear physics. Much attention is directed to nuclear reactors, primarily to the theory of homogeneous and heterogeneous thermal reactors, experimental techniques for determining the critical dimensions of various reactor types, and nuclear fuel breeding. Nuclear-physics, heat-transfer, mechanical, and other properties of reactor materials are considered. Detailed treatment is given of the thermodynamics of power reactors, questions related to the extraction and utilization of heat generated in reactors. Advanced steam turbine and gas turbine designs adapted to nuclear power needs are discussed, in addition to representative heat-exchanger equipment. A special chapter is set aside for the chemistry of uranium, thorium, plutonium, and other materials of nuclear interest.

The second volume discusses problems related to the performance and design of nuclear power reactors. The biological effects of various modes of radioactive radiations, sanitary regulations regarding radioactive contamination of the atmosphere and process water, health physics regulations governing internal and external irradiation are treated. The processes of interaction between neutrons or gammas and matter are described; methods for calculating biological shielding needs and the shielding properties of various structural and shielding materials are cited. The kinetics of nuclear reactor receives detailed treatment, as is the case for techniques and instrumentation employed in monitoring and control of reactor and nuclear power installations. A special chapter is devoted to the instrumentation utilized in reactor construction. In the discussion of chemical problems, particular attention is given to the treatment and management of process water at nuclear electric power stations. The storage and processing of fissionable and high-activity materials, the construction and instrumentation of hot cells and hot laboratories are discussed. A comparison is made of various types of power reactors, and problems concerning the design and construction of nuclear electric power stations are treated. In addition to stationary power reactors, space is given over to portable types, predominantly shipborne reactors, as well as several research and special-purpose reactors.

The principal deposits of nuclear fuel are cited, and a description is presented of the basic techniques used to produce uranium and thorium metal. A series of appendices appears at the end of the volume, those of major interest dealing with reactors now operating, under construction, or being planned, listed systematically. The book is well illustrated and contains much useful tabulated material. A wealth of literature references encourages deeper probing into any particular question. As a whole, the book is written for a broad public of specialists in nuclear engineering and nuclear power engineering.

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